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MONTHLY BULLETIN

OF THE

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

(ENGLISH EDITION)

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BULLETIN
OF THE
INTERNATIONAL RAILWAY CONGRESS
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(ENGLISH EDITION)

[621 .33]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

16th. SESSION (LONDON, 1954).

QUESTION 3.

Technical and economic investigation of the basic characteristics of electric traction systems now in use, with a view to decide whether, and to what extent, there are relevant reasons for preferring one system to another.

In particular, are there any reasons in regard to :

a) power supply;
b) overhead line and fixed track installations;
c) motive power units;
d) working and maintenance costs.

REPORT

(America (North and South), Australia (Commonwealth of), Burma, Ceylon, Denmark, Egypt, Finland, India, Indonesia, Irak, Iran, Republic of Ireland, New Zealand, Norway, Pakistan, South Africa, Sweden and the United Kingdom of Great Britain and Northern Ireland and the territories for whose international relations the United Kingdom is responsible),

by S. B. WARDER,
Chief Officer (Electrical Engineering), The Railway Executive, British Railways.

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I. — Introduction.

This question bears some similarity to Question V posed at the Cairo Congress in 1933 when the choice of systems formed part of the larger issue of the electrification of railways from the economic point of view.

During the intervening twenty years significant changes have occurred in the economic affairs of the world and of railways in particular. There has also been progress with the systems then available, most of which remain potentially of interest to-day.

In addition, an obviously important new system, namely 50-cycles alternating current at about 25 kV on the contact line, has emerged from its first trials on the Hungarian and German Railways, is in use on one French line and in the Belgian Congo, and is being adopted for the electrification of important lines in N.E. France.

During the same period other forms of railway motive power have established themselves, in addition to which new forms of transport have profoundly affected the operational requirements for successful railway work. All these factors give ample justification for considering the question again, particularly as uncertainty as to the system to be preferred inevitably creates an element of insecurity among those responsible for approving railway policy in the matter of motive power.

It is also of some significance to record that during the period under review, some closely reasoned reports have been prepared by eminent authorities for railway systems to which they have been responsible. The conclusions have differed, and indeed four reports each advocate for their particular conditions a different system.

The question in its present form is in two parts, firstly, what are the basic characteristics of the systems in use, and secondly, are they — and if so to what extent — relevant in preferring one system to another.

There would appear to be a difference in emphasis between the French and English form of the question. The former uses the words « raisons pertinentes » the latter « relevant reasons ». The English word « pertinent » is perhaps nearer to the real meaning than the word « relevant ». It conveys better the idea of the matters under discussion having a real, valid, and vital relation to the question to be decided. It is self evident that the basic characteristics of the different systems have some relation, that is, are relevant to the subject. Therefore, the replies now given are based on the assumption that it is the reality, or vital nature of the relation that is at issue.

The question also implies that there may, or even should be, technical or economic or other reasons for supposing that one system is preferable to another. Preferable not only for any particular railway system, but for all railways.

Apart from the investigations already mentioned, every experienced railway electrical engineer becomes, during his career, only too well aware of the merits and de-merits of various systems. None can be entirely without prejudice, and whilst later giving due weight to the replies received from the railway administrations to the questionnaire, it may be useful to consider this matter of the existence of a « best system for all railways » to throw further light on the meaning of the question.

Every electrified railway essentially comprises both (1) fixed installations (overhead contact lines, cables and substations or other power supply installations) and also (2) motive power units and rolling stock. We find when comparing one system with another that some systems show up very well for fixed installations and less well for motive power units; others well for motive power units and less well for fixed installations. The question would be simple if there were a system which is clearly the « best » from both aspects in all circumstances.

Secondly, it is evident that railways differ greatly in their relative content as

regards these two components. At one extreme, some are long simple lines with relatively infrequent trains through country presenting few difficulties by way of obtaining clearances for contact lines at high voltage — in such railways a system which is « best » for fixed installations and less good for motive power units has obvious advantages. At the other extreme, other railway systems, and even parts of one railway, have complicated networks with frequent trains requiring large numbers of locomotives or other forms of rolling stock, passing through towns and suburban and inter-urban country presenting for one reason or another grave constructional difficulties which can only be overcome at vast expense, e.g. to obtain clearance for high voltage contact lines. On such railway lines, the system which is best for motive power units is obviously at an advantage.

Table I gives some particulars showing how two countries compare in these elementary particulars. Therefore unless or until a system is developed which is equally attractive from both aspects, it is clearly impossible that one system would be economically and technically « best » for all countries or even for all parts of any particular railway system.

Thirdly, a railway may have already been more or less completely electrified on one system before a new and better system becomes available. In such a case the new system might need to have very large advantages to make it economically sound to scrap the existing system.

Fourthly, at the other extreme, a small railway system not yet electrified could exist between two larger systems electrified on a system which is neither technically or economically the best for the small railway in question. In such a case considerations such as interrunning would almost certainly be the criterion which would determine the final choice of system.

Once again, therefore, it seems almost certain that one system cannot be economically and technically « best ».

There is yet another consideration of this general nature. Unless low capital costs go hand in hand with low running costs — in the present state of uncertainty about the stability of monetary values and of labour rates throughout the life of a railway there is grave difficulty in assessing which system is economically the best. The capital must be spent over a few years and the investors reimbursed over a large number of years during which the value of money may change and the remuneration of labour for operation and maintenance may change, and owing to political and other influences it must, under to-day's conditions, be uncertain whether these factors will remain relatively stable. Therefore, what could be shown to be the « best » system under present conditions might not prove to be the « best » system throughout the life of all the assets.

Closely allied to this difficult aspect of selecting a « best » system is the fact that the relative costs of materials of differing kinds under world conditions today vary greatly. It will later be seen that the available systems differ greatly in the relative importance of the cost of copper and steel on their economic prospects. Again in some countries, labour is cheap and plentiful, in others some materials are scarce and dear. Clearly in these circumstances, as different systems require for their construction and operation different quantities of such materials and of labour, it is unlikely that one system would be the best for all.

These are some of the reasons why the Introduction to the Questionnaire included an invitation to Administrations to amplify the information they gave, where it was thought this would assist in reaching a conclusion on the main question.

While none of these questions, difficult though some of them are, prevent making as sound a decision about the choice of system for any particular electrification at any particular time, as can be made in respect of any other large investment, they do seem « a priori » to suggest that no one system can be preferable to all others for all railways at this or any other time. In

short, the issues raised in the latter part of the question are certainly relevant, but they are less pertinent, real or vital than would at first seem likely.

For these reasons there were included in the questionnaire the questions 18 and 19.

18. — a) **State one or more of the main reasons which governed the choice of system at the time the choice was made.**

b) *With the knowledge now available and under to-day's conditions would these reasons still be valid?*

c) *If not, which of them no longer apply, and why?*

d) *What system would you choose to-day, and why?*

19. — a) **If you were not influenced by considerations of interrunning with existing electrified lines of your own, or neighbouring railways, and could neglect the cost of re-equipping your existing electrified lines, would you change the system now in use, and to what other system?**

b) *If so, what consideration mainly prevents you from doing so?*

The questionnaire also attempted to produce some comparison in regard to capital and operating costs between parts of the railway systems of different administrations selected by them as typical. It was realised that the fact that electrification had been undertaken at different times would inevitably make cost comparisons difficult and questions were asked to try to eliminate the greater of the probable discrepancies. Also it was felt that the widely differing nature of the various electrifications and the unsettled world conditions that have existed almost throughout the period when electrification has been taking place, would make it almost impossible to base any economic assessment of the relative costs of the various systems on the replies to these questions. The replies that have been received confirm this view.

In brief then consideration of the question itself leads to the view that there are technical and economic factors which are relevant to the question of choice of system, but there are other very important factors in addition to the four aspects specially mentioned. Having regard to some of these additional factors in particular it may be well to introduce the next part of the question — viz: the systems available and their outstanding qualities — by a brief consideration of the reasons for electrifying a railway at all and the possibility of justifying the cost of doing so.

II. — The case for Railways and their electrification.

If the first requisite for a successful railway is that it shall exist or be built between the right places — that is between places where the public wish to travel or send their goods — the second essential is that the trains shall run so as best to suit the public they seek to attract. Failing this the public will certainly turn to other methods of travel, to aeroplanes, buses and lorries, so long as oil and petrol supplies can be maintained, just as they left the coaches and barges for the steam powered trains 100 years ago. The recognition of these facts immediately stresses the importance of the motive power unit and of the freight and passenger rolling stock on the one hand and of the timetable offered to their potential customers and traders on the other, though both are inextricably involved in one another. In the general case, if electrification is to be justified, it must offer what is wanted more cheaply than other types of motive power except,

as in some cases, when it is the only type of motive power that will satisfy the public need.

Owing to a lack of a full appreciation of these issues when railways were first built and to alterations in the public's needs for transport, e.g. by the closing down of certain industries, or transfers of population, and to the legitimate competition of later forms of transport offering services of a quality which the public wants and which in those particular circumstances the railway cannot offer, there are in all parts of the world sections of railways which simply cannot and never will pay their way and which go from bad to worse economically as the public withdraws its custom. Such lines are doomed to be closed down unless strategic or political exigencies demand their retention. These lines have the lowest values of traffic density and do not concern us in general question of electrification or of the choice of systems.

The lines of somewhat higher traffic density are those which are most likely to respond to the cheapest types of motive power. Many of these can best be served by diesel railcars or the like and therefore are not of great interest from the point of view under consideration, although in countries where oil is not a natural product it must be a matter of importance to seek to use in such circumstances a motive power based on home resources and therefore they begin to be interesting from the point of view of electrification and choice of system. But it is important to recognise the fact that the field for competition between diesel, steam and electricity is much more restricted than is often thought, and that in a properly conceived electrification scheme there is a place for all kinds of diesel motive power units.

Lines of higher traffic density and lines on which a high traffic density could be stimulated by the provision of the services the public wants are at the same time those of interest from the net revenue angle to railway administrations, and those of interest as potential electrified lines. Such are the lines with which we are mainly concerned in the consideration of choice of system. Such lines by definition need now, or will need in the future, as the traffic on them grows, because services become available which the public wants, punctual, fast, frequent and comfortable trains. For these lines the motive power unit and rolling stock types are of fundamental importance. It is therefore necessary to consider the relative merits of the available systems in regard to motive power units first, as of primary importance. The other questions of power supply and fixed installation, on this view, are of secondary importance whatever they may cost, because, if they cost nothing and yet involve motive power units and rolling stock of unsuitable qualities, the lines would be useless to the railway administration.

There are other special circumstances which sometimes warrant electrification apart from consideration of traffic, as although intrinsically important, the question being dealt with should be settled for the generality rather than for special cases. The existence of lines of this kind within an administration's network may, however, have an important bearing on the choice of system for electrification.

This further analysis of the general case for electrification again confirms the view expressed in the introduction that there cannot be a universally preferable system. For lines of low and medium traffic density, which for some special reason justifiy electrification, the system giving the lowest overall cost (which will probably be the system giving the lowest cost for fixed installations) is most likely to be remunerative. For lines of high traffic density the system having the best motive power characteristics may well be preferred even over one having a lower initial cost because it is more likely to regain, retain and attract net revenue earning traffic.

III. — Systems of electrification to be considered.

The main systems in use are :

Direct Current	600/750V/800V	3rd or 3rd & 4th rail.	
	1 500V	Overhead contact wire.	
	3 000V	» » »	
Alternating Current.	Single Phase.	16 2/3 cycles.	At voltage varying from 11 000 to 25 000 volts.
		25 »	
		50 »	

There are also some special systems, e.g. a short and successful length of 1 200 V side contact rail, direct current in Great Britain.

There are some systems which are unlikely to be repeated e.g. 3 phase 4 500 V system still in use in N. Italy but which it is intended to convert to 3 000 V D.C., the standard system in Italy.

There are certain systems prospectively likely to be used, e.g. in U.S.A. if a system using the ordinary commercial frequency were to be used; it would be 60 cycles in place of 50 cycles.

The British Transport Commission 1951 Report on Electrification of Railways gives the reasons for the choice and retention of the 600 V third rail system on the Southern Railway of Great Britain and of the 3rd and 4th rail system of the London Transport Executive and explains also why these systems should not be greatly extended. It will be generally agreed that although systems of this type have their justification for certain classes of suburban railways, they have not and will not be extensively used for railway electrification in general.

All these systems have been in use for 25 to 50 years and Table II gives approximate particulars of the total mileage of the main systems in use to-day. The 50-cycles systems were first used on the Hungarian State Railway Budapest to Hegyeshalom, and on the German State Railway's Hollenthal line before 1939. The latter has been the subject of intensive study by the S.N.C.F. since 1945. Their trial line from Aix-les-Bains through Annecy to La Roche has now been in service for two years. It has been indicated that this system will be used for lines in the North and Eastern parts of France, and the section Thionville-Valenciennes is being equipped for operation in 1954. In addition, a mineral line — in the Belgian Congo — is also in service on this system, and trials are being made on a short section of line in Great Britain. The possibility of using industrial frequency on the contact line is thus at the present time a matter of great interest in many countries which are not yet fully committed; in the North American continent certain problems might be accentuated by the standard frequency being 60 cycles.

We can therefore restrict our consideration to the following four main alternatives, viz :

Direct Current :

a) 1 500 V.

b) 3 000 V.

Alternating Current Single Phase, 11 — 25 kV :

a) at low frequency, 16 2/3 or 25 cycles differing from the frequency of general supply.

b) at 50 cycles or 60 cycles according to which is the frequency of general supply.

IV. — Motive power units.

In Section III reasons were given for restricting this study to four main systems : two D.C. and two A.C. Motive equipments of proved success are available for the first three of these systems; in a general way it may be said that D.C. equipments tend to be cheaper in first cost and maintenance than A.C. equipments of similar perform-

ance, and that the lower voltage D.C. equipment presents fewer design problems and is likely to be slightly more flexible and reliable in service. A greater number of motor groupings are possible in the lower voltage systems, due to difficulties in designing a motor to work satisfactorily on 3 000 V and a greater number of economical running speeds are therefore available. The fourth system mentioned — 50 cycles A.C. — has been little used as yet, but progress already made indicates that successful schemes can be developed.

For all standard D.C. systems resistance notching is employed. Though for large outputs this involves the provision of considerable weights of resistance material and the dissipation of considerable amounts of power when starting heavy trains, these may be kept to a minimum by arranging for the resistances to be cut out fairly early in the notching in each motor combination, further speed regulation being obtained by a wide range of field control.

The A.C. traction motor has an inherent tendency to bad commutation as compared with its D.C. counterpart, due to the parasitic induced voltage set up in the armature coils during short-circuit of adjacent commutator segments under the brushes. To reduce this voltage to a minimum it is necessary to adopt a low motor voltage and frequency; a transformer is in any case normally required between contact lines and traction motors.

However, while the low frequency imposes difficulties on the power supply system, the transformer can be made to yield two advantages; it renders the motive unit equipment independent of contact line voltage, so that the most suitable value of the latter may be chosen from the power supply viewpoint; and it introduces a most convenient and economical method of traction motor control. Modern developments have made possible the use of tappings on the high voltage side of the transformer, thus avoiding the switching of the very heavy secondary currents, resulting from the use of a low motor voltage, and the necessary switching arrangements may be incorporated with the transformer itself, thus producing a very compact control unit.

In the course of years the A.C. traction motor has become a very reliable machine. Just as D.C. motor characteristics were improved by the addition of the interpole, so shunting the A.C. interpole in one or more stages has not only considerably improved the low frequency A.C. traction motor, but has also brought highly promising developments in the commercial frequency field.

Nevertheless, although very great strides are being made in A.C. commutator motor design, it is still true to say that the D.C. motor has a better traction characteristic than its A.C. counterpart, for the A.C. motor has a relatively poor starting performance, and it shows to better advantage in the higher speed ranges. For this reason it gives a good performance when hauling fast trains of medium weight; on heavy freight service unduly large outputs are required in order to accelerate the train quickly through the zone of poor commutation and so avoid serious burning of the commutators.

Since the risk of commutator damage due to the motor being held at a standstill by failure to start the train increases with the frequency, flexible transmission systems between motor and driving axle are usually considered desirable for low frequency systems and essential for commercial frequencies.

The reliability and flexibility of the D.C. traction motor and the advantages of high contact line voltages render attractive the combination of the two systems by the interposition of a convertor between line and motors. Rotating machines are in use for this purpose, but the resulting locomotive is apt to be heavy and of reduced energy efficiency. Recent developments in the ionic convertor sphere have however opened up a new field of action. The Pennsylvania locomotives shown in Table III have ignitron rectifiers fed from a 25 cycle

contact line and supplying D.C. traction motors. Other similar units are in service and under construction on other railways using both ignitron and multiple anode rectifiers, and results so far achieved are encouraging. Provided that the problem of clearance from live metal at high voltage and some problems which can be bulked under the heading of « interference » can be satisfactorily settled there should be a considerable future for this type of electrification, since the problem of reconciling the opposing frequency requirements of supply system and traction motors is eliminated.

Moreover, interrunning with existing D.C. systems is considerably simplified; the New Haven railroad motor coach shown in Table IV is able to run both under an 11 000 V 25 cycles wire and on a 650 V D.C. conductor rail system.

Modern developments have thus presented a considerable choice of designs for motive unit equipments. Earlier difficulties in accommodating an A.C. « direct » motor in locomotive and coach bogies have been gradually overcome; this is of especial importance in motor coach work where the small space available under the floor often presented an awkward maintenance problem.

Further advantages of the A.C./D.C. system lie in the high energy conversion efficiency and uniformly high power factor as compared with the direct A.C. motor, and in the possibility of mass production of standard components and ancillary equipment. If by these means first and maintenance costs can be substantially reduced, a type of commercial frequency A.C. electrification might be developed which would have a very wide application.

However, though the traction motor is now freed from the necessity of rigidly conforming with the supply characteristics, the interposition of converting equipment must necessarily affect adversely both maintenance and first costs, and it is probably true to say that the D.C. traction motor, with a wide range of field weakening and with resistance control, operating at 750 or 1 500 V, is and will remain the simplest, cheapest and most reliable form of motive equipment.

The varying characteristics and aptitudes of the tractive equipments available briefly outlined above show fairly conclusively that, as with the other components of electrification, there can be no « best » system of universal application to all operating conditions.

The review just made refers to the technical side of motive power design and to the economics of this technical survey; but there is another and very important field of study which can be legitimately included under the « economic consideration » of the question.

There is one important particular in which the rolling stock differs from power supply and distribution — it is the component with which the railways' clients have direct association. Breakdowns in substations and feeder networks can usually be prevented from having any effect on traffic movement. Alternative supplies can be used, or the track voltage may be allowed to fall below the normal average; the margin of power in the electric rolling stock can, generally speaking, ensure that schedules are maintained. Reliable timekeeping is of great importance.

A failure on a locomotive or motor coach, however, usually obtrudes itself at once on the customer; there is delay en route, missed connections and late arrival of goods, and inevitably, some loss of goodwill; in short, it is a bad advertisement for railway service.

Reliability should therefore be a basic requirement for electric rolling stock; but this is not the only consideration. In Section II it is emphasized that railway services must be punctual, fast, frequent and comfortable. The ease with which speed can be obtained with electrification facilitates frequency, but complicates the problem of comfort. Not only does electric stock usually work at higher all round maximum speeds, but its average speed is

higher than with the steam working it has displaced, so that vehicles run greater mileages in the same time and spend a greater part of their lives in fast running. Wear in moving parts of bogies, suspension, brake gear, etc., for electric stock therefore tends to be accelerated, and careful design is essential if comfortable riding is to be achieved at moderate maintenance cost.

This is important, since in some countries insufficient attention has been given in earlier days to the design of coach bogies and springing, and there has been a tendency for the multiple unit train to be regarded as a necessary evil : a means of travel which was both rapid and frequent, but which offered little prospects of comfort, especially at the higher speeds.

It will thus be seen that the economic aspect of the question includes not only the technical characteristics of the motive power, but also the study of the service characteristics which will best encourage use of the railway and increase its revenue.

If then it is assumed that a railway administration is far-sighted enough to wish to plan its electrification scheme in such a way that its clients will not only be attracted by the speed and frequency of the service from the outset, but will also be induced by further experience both to continue enthusiastic support and to increase in number, the economic and psychological aspects of making the services comprehensively attractive must receive first consideration. That people are insensibly attracted towards « the modern » is the common experience of those who have to sell to the public, and transport should be no exception.

This ideal course of action has rarely been practicable in the past. Comparatively few railways have been built as electrified lines; the majority have been converted from steam operation for the reasons outlined in Section A. With a view to reducing the capital cost of conversion to the minimum it has usually been found expedient to replace the steam motive power by electric locomotives and to continue to use the former rolling stock without change — though some electrifications offer notable exceptions to this process.

For lines which handle predominantly freight traffic this policy was the obvious course. For passenger services, whilst it facilitates speed and frequency, it does not always advance the standards of passenger comfort for reasons given above.

Electric locomotives can also be introduced with the minimum of disturbance to Operating Departments used to working with steam traction; the equipment is concentrated in one unit and open to supervision on the journey by the driving staff; vehicles of all kinds can be easily added to or removed from the train make-up; and the space available in a locomotive enables equipment for any of the existing systems of electrification to be accommodated without difficulty.

Further supporting reasons for their use may be presented from outside. For railway systems which handle international traffic; or which have to work extensively in collaboration with lines still operated by steam, or other systems of electrification, electric locomotives are the obvious and probably the only solution.

In general it may be said that for main line traffic the electric locomotive has been almost universally adopted.

Table III sets out some characteristics of electric locomotives built during the last few years. It will be seen that there is a marked tendency to depart from the type with cab-mounted motors and carrier axles popular some years ago; almost all designs have total adhesion and bogie mounted motors, thus making the best possible use of the locomotive's weight for traction purposes. Axle loads vary from some 15 to 22 tons, and it is evident that in adopting a form of construction which lays the duty of guiding the locomotive on the more heavily loaded motored wheels, one of the problems confronting the designer is that of ensuring that in the higher axle load ranges both riding and the effect on the

track are satisfactory at the highest speeds envisaged. It is significant that with the single exception of the British Railways' Co.Co. locomotive (which has fairly light motors) none of the modern locomotives mentioned are permitted to run at over 70 m.p.h.

A speed limitation of this kind is, of course, not necessarily due to the locomotive itself; it is a combined function of the service speeds and loads, and the maximum allowable axle load on track and bridges possibly not originally designed to cope with electrified working. Higher maximum speeds at these axle loads are in any case permitted in those European countries fortunate enough to have suitable track conditions.

Nevertheless, even if track conditions are adverse, fast passenger services with comfort and frequency standards already presented to the travelling public by road and air operators must be provided if the railway is to survive, and the answer is evident from Table IV. The most significant feature here is that those railways who place what is by modern standards a low maximum speed limit on their locomotives have no hesitation in running multiple unit stock at speeds up to 90 m.p.h. for their fastest passenger services.

For « locomotive » electrification the locomotive stock in general must be heavy and powerful enough to haul the maximum loads to fast schedules; but frequency of passenger service demands a succession of fairly light trains, and if locomotive power is not to be wasted it seems more reasonable to use locomotives of moderate output arranged for multiple unit control. Such locomotives would be much more attractive financially if they could be arranged to carry payload, which again re-asserts the suggestion that the multiple unit train may be pre-eminently suitable for providing safe, rapid, frequent and comfortable transport of a kind which could enable the railways to take a profitable lead once more in this sphere.

With the low centre of gravity and light leading axle loads possible with motor coaches, speeds of 90 m.p.h. and over can be maintained without difficulty over long distances. For the majority of passenger services motor coach stock presents great advantages; and — always with the attraction of traffic in mind — it is of interest to examine some of the characteristics which have made multiple unit electrification schemes so successful in Great Britain and on inter-urban services in many countries.

Terminal working is greatly simplified. The lines are cleared of locomotive movements, and a train is ready to leave as soon as it arrives; the time of platform occupation being solely dependent on time required for passengers to get out and in, and for the train crew to change ends. If changeover crews are provided, even this delay can be eliminated.

The horsepower per ton of train weight is more or less constant. Whatever the length of train the acceleration and speed characteristics are the same; the correct motive power for a given service is thus automatically provided and the schedule can be maintained with any train length up to the maximum allowable.

The distribution of the motive power over a number of axles throughout the train enables the best possible use to be made of the available adhesion, both for accelerating and for electrical braking. This division of power also permits of the use of lighter motors, gear assemblies, bogie construction, and so on; with the consequence that restrictions on running are likely to be small.

As indicated earlier, the failure of a locomotive will often immobilise the whole train. For heavily trafficked lines the delays imposed by a complete train failure, perhaps involving the despatch of an assisting locomotive, can be disastrous, but with a number of individual power equipments it is unlikely that more than one equipment will become defective at any time. If a defect occurs, the equipment concerned can usually be cut out of service

and the train worked to its destination on the remaining equipments with little loss of time.

The concentration of the motive power into one unit results in the production of a massive machine which, even if only for psychological reasons usually demands the presence of two men in control. By comparison, the unobtrusive power equipment of a multiple unit train leaves the driver almost unconscious of the power he controls, and freedom from distracting noise enables him to give full attention to the business of driving.

Sudden illness of the driver can be countered by the usual « deadman » equipment with sensitive controller handle or foot pedal, and one-man control of the train can be used with perfect safety over long distances.

Rapid changes in train make-up to suit traffic conditions or emergencies can be made without the necessity for ensuring the presence of a locomotive at each point.

Finally, the problem of auxiliary power is eased considerably, since auxiliary supplies are directly available on each individual unit for lighting, heating, cooking, refrigeration, ventilation and other purposes. For locomotive hauled trains much of this power is often furnished by axle-driven generators on the various coaches, i.e. it absorbs valuable tractive effort from the locomotive. The elimination of the large steam heating boiler would be generally welcomed.

Against the above advantages it may be argued that a number of motor coach power equipments must necessarily be more expensive than a single locomotive equipment to do the same work. In first cost this is at present true, but economies by enhanced possibilities for mass production and in manning costs and maintenance might well justify the exclusive use of motor coach stock for passenger working generally.

Maintenance savings may be important. The most modern D.C. motor coach equipments on British Railways are designed to operate for 12/16 months without adjustment or other maintenance attention, and experiments are now in hand to develop roller bearing traction motors to run for up to 100 000 miles without addition of lubricant. Similar studies are understood to be under investigation in other countries.

Moreover, it cannot be agreed that its sphere of usefulness ends with passenger traffic. One of the most disconcerting features of the general loss of revenue experienced by many railways is the « skimming » process by which the lighter, more easily handled parcels and freight traffic is taken from the railways, leaving them to carry the awkward, heavy and unprofitable loads. On the roads this traffic is handled by a fleet of lorries which enables it to reach its destination quickly and with considerably less damage than it often sustains during its transit on the railway; and here too is a field in which light, fast parcels motor coaches or multiple unit trains in conjunction with suitable feeder services might score an unexpected success.

It is therefore advocated that though there can be no « best » system to suit all needs of every class of traffic, it might be worth while to develop a wider use of the load-carrying motor coach and the multiple unit train, perhaps somewhat on the following lines (see table hereafter) :

V. — Power supply.

For historical reasons, the railways at first tended to have their own power stations generating power for traction and ancillary purposes and even supplying power to other consumers. In some instances there are still valid reasons for retaining such arrangements for part or the whole of a supply to a railway. These reasons need not be discussed here but in such cases it should be possible to decide all questions of the interaction of the characteristics of various systems of electrification on the power supply in a very definite manner as one administration has

Type of traffic	*Type of service*	*Motive unit suggested*
Low and medium traffic densities.	Passenger and freight services.	Passenger and parcels carrying motors coaches, and multiple unit trains.
High traffic densities	Light freight Heavy freight Special passenger	Total adhesion locomotives (mixed traffic type).
	Passenger	Multiple unit stock.

all the questions under its own control and can select the most appropriate solution taking every aspect into exact account.

At the opposite extreme from this point of view a railway administration may for various reasons have no control whatever over the design and layout of the power system or of the terms on which the power supply authority is prepared to sell its power. It might also be that the railway load is of negligible value to the power supply authority, who might therefore regard its other consumers as of greater importance and impose such restrictions on the railway as would have a marked effect on its decision regarding choice of system.

In the first case, every question concerning the effect of choice of system on the power supply can be settled strictly on its technical and economic merits. In the second case, this is not so and often questions of expediency may be the determining factor.

In actual practice, different railway administrations have to deal usually with power systems lying between these two limiting cases. Reference to the replies to section B of the Questionnaire will show how diverse are the arrangements made for power supply and how different the methods of charging for current.

It is once more clear that the importance of questions concerning the power supply will vary from one railway to another and that no one system of electrification can be *best* in all cases.

The characteristics of a power demand that interest a supply authority are :

(i) where the loads are required in relation to its existing feeder and substation network;

(ii) the size of the load, including questions of the relation of short time loads to loads of long duration and the average load;

(iii) the times at which load is required in relation to the load curve of the supply system;

(iv) the power factor of the load;

(v) any qualities of the load which distort the wave form of supply or in this or other ways affect the quality of supply given to other consumers.

The characteristics of a power supply that interest a railway administration are :

(i) the cost of current and method of charging;

(ii) the convenience, capacity, regulation and reliability of the supply;

(iii) the duty imposed on any railway owned switchgear and cables under short circuit conditions;

(iv) the proneness of the supply to be disturbed by factors such as those mentioned in (v) above.

If then these are the characteristics of the power supply system with which we are primarily concerned, the characteristics of the systems of electrification enumerated in

Section III in regard to them may now be considered, when it will be seen that the question of substation spacing occupies a prominent place in the investigation for D.C. and A.C. systems alike. In spite of this, however, it should always be borne in mind that a high proportion of substations on any railway site themselves at important junctions where essential track sectioning facilities can economically be obtained in substations and so avoid the building of separate cabins for that purpose.

For direct current systems, whether power is generated or purchased, it must (except in some negligible minor cases) be delivered as H. V. alternating current to substations for conversion to direct current. The voltage may vary from 6.6 to 110 kV. The motors of the motive power units will be designed for either 1/2 or for the full contact line voltage, as there is not at present any conveniently practicable method of using a higher voltage on the contact line and a lower voltage on the motors, as mentioned in Section III.

In order to avoid unduly wide variations in voltage on the contact wire and coincidentally an uneconomic power loss in the overhead contact system, whilst at the same time taking into account the practicable economic conductivity of the overhead system and the necessity of being able to isolate faulty sections of track or equipment automatically, these systems are characterised by relatively close spacing of substations for the conversion to direct current.

Table V gives typical substation spacings for both voltages and although no general rule can be evolved because each section of line must in principle be considered on its merits, the mean distance apart of substations is likely to be of the following order :

1 500 V. 7 miles varying 5 to 15.
3 000 V. 15 miles varying 10 to 30.

For alternating current systems operating at frequencies other than that of the national supply network, either a separate low frequency supply network must be run throughout the railway system to supply the contact system at suitable points or alternatively frequency changers must be installed in substations fed from the public supply network.

The first method involves costly feeder networks and although industrial loads can be supplied by the installation of frequency changers, this seems likely to be usually not commercially attractive since these networks tend in an industrial country to duplicate those of the supply authority. The second method involves costly substations with a rather poor efficiency, particularly at light load, but with the possibility of providing leading wattlers which may be (and in Sweden, for example is) of sufficient commercial value to compensate for the additional losses in the frequency changers.

To avoid excessive impedance drop in the overhead system and for reasons of economy, the current in the overhead system must be kept to a low value and it is impracticable, and incidentally for reasons explained in Section IV, undesirable to run the contact system at motor voltage. These systems therefore include transformation from contact line to motor voltage on the motive power unit and the contact line is operated at the highest voltage, e.g. 11 or 16 kV, which is considered economically practicable. Longer distances are permissible between substations, and Table V also gives typical substation spacings for both voltages. It is evident that the character of the railway system has a great influence on the spacing of these high voltage systems, and that no useful generalisation can be made.

In contrast, alternating current systems at the frequency of the national supply network do not intrinsically require either frequency changers or special supply networks, although some switchgear is necessary in substations at the places where supplies are taken, and transformers are also needed. As in the case of low frequency systems, it is impracticable to operate the

contact system at motor voltage and as impedance drops are proportionately greater it would appear that the contact line must be run at a higher voltage and substations must be more closely spaced for equal efficiency of distribution in the overhead contact system. For this reason, it seems unlikely that voltages much lower than 25 kV would be commercially attractive and that the mean spacing could then be expected to be of the same order as with a similar railway using low frequency. The use of locomotives of the motor convertor type arranged so that the field of the motor can be adjusted so as to give unity power factor would allow larger spacing.

Unless the railway runs through undeveloped country, it is generally possible with the alternating current system to obtain supplies from the general electricity supply network at the places where it is required and so avoid the expense of feeders distributing to more than one substation. This is less likely to be the case with the direct current systems, but in closely developed countries such as the Netherlands, it has been found possible to locate substations where supplies can be obtained even for a 1 500 V system and an extension of this system may be expected with corresponding benefit to the cost of fixed installations. This, not only because H.V. feeders no longer need be supplied and maintained, but also because as the supply substations are relatively small, the switchgear may be of considerably smaller rupturing capacity with correspondingly smaller cost than it would be if current were purchased in large blocks through major substations. This benefit would be accompanied by loss of diversity, which might, in certain cases, involve additional current costs as well as requiring converting plant capable of higher short time duty. This latter requirement does not present any great difficulty.

Serious difficulty with bad power factor is only likely to occur on 50-cycles electrification using 50-cycles traction motors, since the power factor of multiphase rectifiers supplying D.C. electrification is higher than the average commercial power factor and that of low frequency alternating current systems and of 50 cycles systems using motor converter locomotives can be made equal or superior.

Considerable unbalance must occur in 50 cycles electrification at the supply point. The extent of this will clearly depend on the number of tracks to be fed and the frequency of train movements in the neighbourhood of the supply point. The unbalance can be mitigated by the use of Scott connected transformers. The effect of the unbalance (particularly of harmonic unbalance if rectifier fed motors are used in the motive power units) will need careful investigation with the supply authority. Whilst it must be stated that it is understood that the French supply authority does not anticipate serious inconveniences on these accounts, it remains a fact that the method of feeding tracks must be controlled not by the requirements of railway convenience only, but also by the need to reduce out of balance to a minimum and that even when this has been done, all the other consumers have to dispose of the distortion caused by the unbalanced railway load.

With direct current electrification, corresponding care must be taken to avoid harmful distortion of supply by harmonics caused by rectifiers. With adequate cooperation between the railway and the supply authority serious difficulty has been avoided.

VI. — Overhead line and fixed track installations.

These installations comprise :

a) *high Voltage feeders* connecting substations to points of supply;

b) *substations and their equipment* including track feeders connecting the D.C. busbars to the overhead line, intermediate track sectioning cabins and their circuit breakers where justified, apparatus for remote control and

control stations and supervisory cables and pilots;

c) *overhead contact line* and its structures and foundations and track sectioning switches and bonding of structures to tracks and of rail to rail;

d) *any special equipment* associated in certain systems with prevention of undue drop in contact lines or of interference to railway or other pipes and cables and equipment.

High voltage feeders.

It has already been shown in Section V — Power Supply — that the necessity of high voltage feeders can only be established for each individual railway after a close analysis of the relative economy of taking supply at each substation or of supplying or purchasing in bulk.

Two generalisations only are possible. First, that as the public supply networks develop, the need for railway owned feeders should progressively diminish, and their disappearance would not be regretted. Secondly, the higher the voltage, whether D.C. or A.C., the less likelihood there is of their being necessary, but, as already mentioned, in industrial countries, even at 1 500 V they should rarely be needed throughout.

When high voltage feeders are necessary, they can theoretically take the form of overhead lines or of cables. The choice again depends on their capacity and length and on the kind of country traversed by the line, and must therefore be settled for each case individually. Where 11 or 33 kV are appropriate voltages, it will usually be found that the other conditions involve the use of cables. In these cases, there is little doubt that the best solution is to suitably protect the cables and bury them where the terrain allows this, and failing that, to give continuous support and protection by installing them in concrete troughing. The use of oil filled cables for 33 kV or 66 kV promises savings in this part of the cost of electrification.

Where higher voltages are necessarily required, the railway probably runs through undeveloped country where open lines are a practicable solution. The temptation to economise by using the overhead track structures to support overhead H.T. feeders should generally be avoided. When a serious derailment occurs, there is quite sufficient handicap in having to dispose of the overhead system for the lines without complicating matters further by having to disturb supplies to adjacent substations.

Substations and their equipment.

More or less switchgear will be needed in the aggregate according to the number of substations as determined by substation spacing for the particular system. The kind and arrangement of high tension switchgear will be almost independent of the system of electrification and dependent solely on the characteristics of the supply and the country involved.

If space is cheaply available and climatic conditions permit overhaul and maintenance at any time, outdoor switchgear may be economical at 33 kV and above, otherwise standard indoor types are suitable and desirable.

In direct current systems, the use of mercury arc rectifiers has become established as regular practice, and whether to use sealed steel or glass bulb rectifiers, or pumped air cooled rectifiers or ignitrons seems to be a question of local expediency governed rather by local customs as to cost rather than any real difference in performance. The choice of number of phases is dependent on supply conditions, 12 phase connection being generally satisfactory. Reliability is very high and maintenance negligible so that the investment in spare capacity can be reduced to a very low value by judicious choice of substation location and rectifier duty cycle. When regenerative braking is desirable, and sufficient inducement is available, South African experience shows that grid controlled rectifiers operating as inverters can be satisfactorily

employed, but in certain cases the main advantages of regeneration can be obtained by installing loading resistances with electronic control at appropriate substations, with normal rectifiers.

In alternating current low frequency systems, although in theory grid controlled rectifiers could be used, it seems likely that the well tried practice of using rotating machine type frequency changers will continue as, instead of providing rather difficult harmonic disturbances, their motors can be compensated so as to produce leading wattless current which, as in Sweden, is a valuable saleable commodity both to compensate for bad power factors of other appliances and to increase system stability and reduce overall cable loadings. This goes a long way towards compensating for the lower efficiency of frequency changers.

In 50 cycle alternating current systems, whilst the same advantages could be obtained by using phase converters, so avoiding most of the drawbacks of this system of electrification from the supply and railway operation point of view, the need for securing the utmost economy in the cost of fixed installations seems likely, as far as evidence is at present available, to lead to supplies being taken through isolating transformers with 2 phase/3 phase connections so as to reduce the out of balance.

Whatever the system of electrification, the substations must necessarily contain high speed circuit breakers for automatically disconnecting any faulty section of track from the remainder. These may also be required between substations. Whether or not this is so depends on a number of factors peculiar to each railway electrification, including the lowest circuit breaker settings that are permissible without causing unwanted trippings under both normal and abnormal traffic conditions, the economically permissible section of the contact wire/catenary system, and the location of points where isolation is needed to suit Operating Department needs.

It is an advantage of direct current systems, that subject to the above qualifications, any number of substations can be operated in parallel whereas care must be taken on alternating current systems to avoid unsuitable couplings between points of supply.

With direct current systems of the size under consideration, it is now invariably economic to instal remote supervisory control of all substation equipment and even of track isolating circuit breakers. Not only is this necessary from the point of view of restoring supply after occasional failure of items of equipment, but it is also desirable for routine maintenance. Normal developments of orthodox telecommunication equipment have given satisfactory results. The labour cost formerly associated with the manning of substations thus disappears from the drawbacks of the lower voltage systems and with suitably designed equipment the expense of maintenance becomes truly negligible. The necessary pilots for remote control and for telecommunication between substations, track and control room and for operation of selective protective relays for high tension feeders, if these are necessary, can be combined in one suitably designed cable laid adjacent to the feeder cables, if any, or disposed as they would have been laid.

In high voltage A.C. systems using frequency changers, the long distance between substations generally precludes the economically successful use of supervisory systems and substations are normally manned.

Overhead contact line.

The choice of system affects the design of the overhead contact system in two ways. The higher voltage A.C. systems permit the use of very light contact lines. This not only reduces their intrinsic cost but permits also the use of certain types of supporting structure which are commercially impracticable for heavier overhead lines.

The actual size and disposition of conductivity between contact wire or wires, catenary and auxiliary catenary, if any,

essentially varies according to traffic density, train weight and substation spacing, but in the average case of a main line or heavy suburban railway, the order of magnitude would be :

1 500 V. D.C.	from 0.5 to 1.0 sq. in.
3 000 V. D.C.	from 0.25 to 0.5 sq. in.
Low frequency A.C. / 50 cycles A.C.	from 0.15 to 0.25 sq. in.

It is a matter of great difficulty to give values which will not be misleading for the corresponding cost of overhead systems, and for the reasons stated in Section VII the replies to the Questionnaire do not afford the desired data.

Costs per single track mile are generally used in comparative statistics, but according to the number of lines spanned and the difficulty of the work, this may vary over a very wide range.

Taking the lower values of conductivity given above, the probable normal range of cost per single track mile at the prices ruling in January, 1953, would be of the following order :

1 500V.	£6 000 - £9 000	According to the complication of the line in question.
3 000V	£5 000 - £7 500	
1 phase A.C.	£3 000 - £6 000	

If the higher voltage systems are better suited to railways in open country, it is largely because of the lower costs per S.T.M. which apply in those cases over long stretches of line often of very simple and even single track type.

On the other hand, the higher voltage A.C. systems necessarily demand larger and more expensive insulators (which do not greatly increase the cost), but also much larger air clearances both to fixed structures and between contact wire and locomotives, rolling stock and freight loads.

Certainly in the D.C. case, the clearance must be based on the over-potentials reached during voltage surges and in either system and on lines in lightning areas, additional clearances may be advisable and in any case a factor of safety must be allowed for loss of adjustment, e.g. due to ballasting track settlement, temperature changes, etc., so that the desirable clearance cannot be determined purely by laboratory tests of flashover distances at the nominal voltages.

Apart, therefore, from questions of governmental regulations, which could no doubt be revised on good cause being shown, it would seem that the minimum clearance under normal temperature conditions should not be less than the values shown below :

1 500V D.C.	3″	absolute	6″	desirable
3 000V D.C.	5″	»	8″	»
16 000V A.C.	10″	»	15″	»
25 000V A.C.	15″	»	20″	»

and that where there is any risk of steam traffic passing under the wires at least the higher of the two values should be used.

It is here that the main difficulty in assessing the general position of the higher voltage systems occurs because the cost of obtaining clearances, particularly on railways constructed some time ago, through urban districts with frequent tunnels and overbridges, arises. Much economy can be achieved by close co-operation between the civil and electrical engineer and in the limit special steps could be taken, e.g. coasting through short obstructions or at considerable expense and with certain other drawbacks by the use of lower voltages on long difficult obstructions such as tunnels.

The cost of such works will clearly vary greatly from one system to another, but it is quite easy to spend on altering one overbridge as much as a single track mile of overhead construction.

In one example in Great Britain, the cost of structural alterations has been 15 % of the cost of the overhead equipment (including structures and foundations).

It is clearly almost impossible to suggest an average figure for the cost of obtaining clearances, and with very great reserve it is suggested that values of the following order must be regarded as probable; lower

values would obtain on lines in open country, whilst higher values would obtain over many parts of lines in the immediate neighbourhood of a capital such as London.

1 500V D.C.	£1 000
3 000V D.C.	£1 250
16 000V A.C.	£2 000
25 000V A.C. 50 cycles	£3 000

The bare addition of these estimates leads to the following estimate, subject to all the qualifications already mentioned, of the total cost of constructing one S.T.M., viz :

1 500V D.C.	£7 000 — £10 000
3 000V D.C.	£6 250 — £ 8 750
16 000V A.C. low frequency	£5 000 — £ 8 000
25 000V A.C. 50 cycles	£6 000 — £ 9 000

There are other aspects which demand attention. There remain considerable differences of opinion and need for further investigation on questions such as the best way of securing minimum wear with sparkless collection — it has been alleged that double contact wires are necessary at 1 500 V but this seems open to question and alternatively should not greatly increase the total cost of providing the overhead system. There is no doubt that further improvement in pantograph and overhead line design, with perhaps the development of self-lubricating high conductivity collecting strips will reduce operating and maintenance cost. For the moment it seems certain that the H.V. systems have a real advantage here over the D.C. systems. They are also immune from electrolytic troubles due to leakage currents which inevitably increase either the first cost or the maintenance cost, or both of insulated fittings on D.C. systems.

The strength needed in the supporting structure is clearly dependent on the cross section of copper and the higher voltage systems are here at an advantage.

Certain factors often reduced this advantage. Most lines and their supporting structures must be calculated for strength under combined ice and wind load, although ice formation on the contact line is very unusual provided traffic working can be maintained in spite of permanent way blockage, difficulty at points, etc. However, it must always be reckoned with as a possibility once or more in the lifetime of most railways. The effect is that whereas the copper section of a 25 kV A.C. system may only be some 25 % of that of a 1 500 V system in normal conditions, with ice load the area offered to wind may be about 66 % of that of a 1 500 V system. As a greater « blow off » and greater sags cannot be tolerated, and in fact lower values may be necessary if narrow pantographs are to be used to cheapen the cost of obtaining side clearance, the structure spacing must be much the same for a high voltage A.C. as for a lower voltage D.C. line. The greatest possibility of economy in overhead support costs, namely, by the reduction in the number of structures and points of insulation is thus lost. The main economy that is possible is in the size of individual structures and foundations, resulting from a reduction of the order of 25 % indicated above. It is often remarked that high voltage contact lines look very much lighter than, for example, 1 500 V D.C. lines. This lightness is often illusory and is due, other circumstances permitting, to the greater use of simple post and cantilever structures. This type of construction is certainly easier to design economically the lower the forces to be resisted, but the basic reason for the apparent lightness of H.V. A.C. overhead line structures is generally that in the countries which use this system there is much single track work and good clearance between tracks and at the side of tracks. Where such conditions prevail on railways with D.C. electrification, as in parts of Italy and on lines now under construction near Copenhagen, similar advantages can be obtained.

Further, many of the detail items are either almost independent of the voltage and some more costly at the higher voltage. For structures spanning several tracks, the cost of preparation and of painting or

other preservative treatment is not greatly reduced for a light structure — the cost of registration of wires is nearly the same for any voltage — the cost of insulation is higher, the cost of bonding to and of the track and of drawing office work, of fabrication, of site organisation, inspection and testing are nearly the same per structure irrespective of its weight if it spans the same number of tracks. The saving possible on H.V. structures of the same type is therefore much smaller than would be anticipated at first sight from consideration only of the lower conductivity permissible in the higher voltage contact system and is mainly that due to lower weight and greater ease of erection.

Certainly every reduction in the load on a structure, under both normal and emergency conditions, offers, in addition to the savings already discussed, opportunity to use a wider range of structure types, though, as mentioned above, the type and cost of structure is far more dependent on the number of tracks spanned and the possibilities in regard to footings. Where timber is cheap and good, timber poles, which are rarely permissible on 1 500 V schemes, may be practicable on H.V. schemes as, for example, in Norway and Sweden, on single track sections of line. There is a stronger case similarly for tubular steel poles and probably for prestressed concrete poles on single track lines, particularly on H.V. systems. One of the important questions at the present time is that of the extent to which the use of prestressed concrete is justified. Ordinary reinforced concrete has proved to be so much heavier and liable to accidental damage in handling and erection as to have no real advantage over steel, but these disabilities are greatly reduced by using prestressed poles. Such poles give good prospect of reduced maintenance costs by elimination of painting, but there is some doubt as to their ability to withstand shock loads. They are at their best as masts for cantilever types of support and seem to be unsuitable for structures spanning more than four tracks. They will therefore be most suitable for H.V. light weight lines with simple track formations, where, incidentally, inconvenience by shattering instead of bending if hit in a derailment would be of less consequence. Multiple track D.C. electrification seems to give this construction the least scope to be decisively better than the conventional types of steel mast or gantry and probably only a realistic estimate in particular cases could prove whether there would be enough saving in cost to balance the risk of delays on all tracks if a structure were shattered. Great as is the need to find a type of structure which will not require regular preservative treatment, it seems doubtful if the overall advantage of prestressed concrete will in such cases be as great as was hoped for, though for simple track work there is little doubt that they will be widely used.

So far little reference has been made to the closely allied question of foundation type and cost. Much work has yet to be done on the factors involved in designing these for the minimum cost — not least on the problem of a reliable, efficient and expeditious method of determining soil values on a railway running through poor and variable terrain.

It is certain that the cost of foundations for any particular track formation depends to a much greater extent on the nature of the soil than on the choice of system for electrification. For example, in double or quadruple track work in poor soil, the total cost per structure, including foundations, will be appreciably less for a B.F.B. portal structure than for any type of post and cantilever structure. In such cases, therefore, the D.C. systems for which portal type structures are specially suitable will be at little, if any, disadvantage over the H.V. A.C. systems. In rock this would be less certain and on single track work or on double track work in good soil, where mechanical construction of foundations and planting of poles is feasible, the H.V. system will reap almost the full benefit of the lower loads.

VII. — Working and maintenance costs.

It has proved to be impossible to make any effective comparison of either the initial or the working and maintenance costs from the replies received to the Questionnaire. The main reasons are, of course, that the lines were electrified at different times and that the differences between the systems effectively obscure, even if full and strictly comparable costs had been supplied, the differing costs of the methods of electrification under comparison. The fact of the lines having been electrified at differing times involves the use of imperfect multipliers to bring first costs and working costs for capital and depreciation on to a common basis. It also means that maintenance costs for old equipment of one railway are being compared with costs for new equipment on another. It has already been shown in previous sections that comparisons between lines differing so greatly in characteristics are essentially unsound for comparing different methods of electrifying them. Moreover, effective comparison of maintenance costs between one railway and another is only possible, if at all, after minute examination of accountancy methods and debatable adjustments for differences between the size of maintenance units and methods. The differing methods by which payment for current is made and the arbitrary nature of adjusting from one currency to another and from one year to another, which ignore differing ability, skill and diligence between craftsmen and artisans, are two more obstacles to any real comparison between the costs of doing the same job on different railways at one time and make comparison between different jobs at different times wellnigh impossible.

In these circumstances, an endeavour has been made to assess the cost of electrification for two simple imaginary lines of equal single track mileage at 1 500 V D.C. and 25 kV single phase 50 cycles A.C. The characteristics of the first line have been deliberately chosen, as favourable to electrification using direct current. Heavy traffic, say 5×10^6 trailing ton miles per year per single track mile through industrial country where power supplies are directly available at two-thirds of the substations, where clearances are difficult to obtain. The characteristics of the second line have deliberately been chosen as favourable for electrification using alternating current at high voltage. Light traffic about 1.1×10^6 per S.T.M. per annum through undeveloped country, where power can only be obtained at places far apart from one another involving heavy expenditure on feeders to substations, where clearances are easy to obtain.

It is believed that the value assigned to the main items of cost, shown in Table VI, which have no foundation other than personal judgment, are tolerably comparable and do not deliberately favour one system more than another.

If this be so, this comparison shows that on the heavy traffic line there may well be nothing to choose when all factors are considered between the two systems, but that there is a marked advantage in adopting a high voltage system on long lightly loaded lines. There can be little doubt that this is the truth of the matter and that it will be equally reflected in working costs. The vital questions are the cost of obtaining clearance for the high voltage system and whether the estimate of 15 % additional cost on Motive Power Units is correct. Clearly a comparison of this kind can only give a general picture. Special factors, which always exercise a controlling influence, may well be of more importance than the choice of system in determining the cost of any particular electrification project.

VIII. — Other considerations.

The most important of the other considerations affecting the choice of system seem to be :

a) interrunning at boundaries of railways electrified on different systems;

TABLE VI.

Estimate of relative capital costs for electrification.

Particulars of line	Short heavy traffic 90 route miles 400 single track miles 72 Motive Power Units		Long light traffic 360 route miles 400 single track miles 24 Motive Power Units	
System	1 500V D.C.	25 kV. A.C. 50 cycles	1 500V D.C.	25 kV. A.C. 50 cycles
	£.	£.	£.	£.
Overhead Line	3 600 000	2 400 000	2 400 000	1 200 000
Clearances	400 000	1 200 000	100 000	200 000
Motive Power Units	3 200 000	3 700 000	700 000	800 000
Substations and feeders	800 000	300 000	2 400 000	200 000
Signal modifications	300 000	600 000	100 000	200 000
Telecommunication modifications	300 000	400 000	1 000 000	1 100 000
	8 600 000	8 600 000	6 700 000	3 700 000
	100 %	100 %	100 %	55 %

b) interaction with other services, e.g. signals, telecommunications, etc.;

c) electrolysis.

The retention of existing facilities for the passage of trains from one part of a system to another or from one country to another may well demand that provision is made for motive power units to work on either or both of two different systems. In general, if both systems employ direct current motors, this requirement can be met without undue difficulty by suitable choice of motor voltage and circuit arrangement, generally at increased cost. In that case it then remains to settle the disposition of neutral sections between the two contact systems as regards length and safety precautions. Consideration will also need to be given to the question of whether the pantographs will work equally well over both railways. The only generalisation that seems to be possible is that these problems will present greater or less difficulty in some cases than in others, but that in any given case they can be overcome at an expense which seems unlikely to govern the choice of system.

It is equally difficult to be explicit about the importance of the interaction between the contact wire and signals and telecommunications. The replies to the Questionnaire confirm that whichever system is adopted, it has in fact become a custom to cable open telecommunication circuits. Attention is drawn to the comment of the Swedish State Railways that when the number of circuits involved exceeds a relatively small number, the saving in maintenance costs outweighs the cost of cabling. It seems doubtful if this aspect is always given full weight in estimating the financial effect of electrification. It would also seem that allowance should be made for

the improved facilities that obtain when a telecommunication line is cabled throughout its length.

The cost of modification to signalling circuits will clearly vary considerably, depending on the nature of the line and the systems of signalling and electrification in question. In this case, it seems likely that the costs involved with H.V. 50 cycle electrification will be greater than those involved with other systems, and this opinion is reflected in the values used in Table VI.

Reference has already been made to the advantage that A.C. systems have over D.C. systems, as regards electrolytic effects. Reference to the schedules will, however, confirm that even in the case of D.C. railways, these effects are generally of negligible financial importance.

Finally, it may be said that as regards both *b*) and *c*), and incidentally with regard to the steps to be taken to avoid excessively high potentials on the running rails or excessive voltage drop at the motive power units, the soil resistivity is of great importance and varies widely from one country to another, so that in Sweden for example the provision of a return conductor is considered necessary.

IX. — Conclusion.

The schedules in Section X contain the main replies to the Questionnaire circulated to the various Administrations. It was realised that a comprehensive reply to all the questions was a formidable task for any Railway to complete in the time allocated and accordingly your Reporter wishes to express his grateful thanks to those Administrations who have supplied the information requested.

The variety of the answers received created obvious difficulties in presenting an analysis in tabular form and this led directly to the discussion of the meaning of the question in the Introduction (Section I). It is here suggested that in seeking the pertinent reasons for preferring any system, detailed investigation shows that there can be no one system which can be preferable to all others at this or any other time. Section II draws attention to factors other than the technical and economic elements relevant to the choices of system by discussing the general case for electrification and in Section III reasons are given for restricting the study to four main systems, two D.C. and two A.C.

The rolling stock aspects of the Question are dealt with in Section IV and this is perhaps the most important part of the Report introducing as it must necessarily do, the operational requirements of meeting the demand for transportation. The analysis given of the varying characteristics of the tractive equipments available also demonstrates that there can be no « best » system of universal application to all operating conditions.

Attention is also drawn to one particular feature which electrification can achieve which is not so conveniently possible with other forms of motive power. Given sufficient attention to the design of bogies and coach construction, considerable benefits would be derived to operators and public alike of improved multiple unit train sets, and in developing this theme suggestions for suitable motive power units are recommended in the following table.

Power supply problems are dealt with in Section V where it is deduced that these are largely associated with the National power supply system which in itself is or has been determined by historical and geographical circumstances. The influence of the main power supply is more likely to be directed to electrification as a policy rather than to the type of systems.

The fixed equipment comprising high voltage feeders, substations and overhead contact lines together form the heavy investment which any electrified railway has to assume, and which, because of the ever present problem of raising the required capital sums, is the dominating issue. The cost of these in relation to the

Type of traffic	*Type of service*	*Motive Unit suggested*
Low and medium traffic densities.	Passenger and freight services	Passenger and parcels carrying motor coaches, and multiple unit trains.
High traffic densities	Light freight Heavy freight Special passenger	Total adhesion locomotives (mixed traffic type).
	Passenger	Multiple unit stock.

cost of the railway as a whole is liable to be grossly over estimated.

Section VI draws attention to the factors involved in each type of system and discusses in some detail the reasons why the high voltage 50 cycle system is potentially so attractive. It also points out that the advantages of the high voltage system, insofar as the contact wire is concerned, are not necessarily realisable.

The wide diversity of the replies received concerning the first cost, the working, and the maintenance costs made it impossible to make effective comparisons. Detailed reasons for this are given in Section VII and in attempts to secure a relative assessment of the respective costs, a financial comparison has been made on two widely differing types of railway systems with cost figures regarded as being representative of present day levels. The conclusion to be drawn from this study also supports the view which has already been deduced in the various technical aspects of the problem, that no one system is likely to be superior to all others in all circumstances.

In short, it is not possible to demonstrate that there is in existence to-day or in the forseeable future one best system for all conditions. We can, however, quickly determine the best system for any given conditions, and it is suggested that the information contained in this Report, reflecting as it does the practice and experience of some 40 years of electric traction, is still valid for this purpose.

Improvements in design and performance will, of course, continue and costs will be favourably influenced by such developments, particularly if electrification expands. It is, therefore, satisfactory to record that the art of railway electrification has been developed on sound practices and should continue to prosper.

SECTION X.

SCHEDULES.

TABLE I.

Contrasting types of railway.

	Belgian Congo	British Railways Manchester-Sheffield-Wath.
Route Mileage	65	75
Single Track Mileage	65	228
S.T.M./Route Mile.	approx. 1.0	3.0
No. of locomotives.	12	65
Locomotives per route mile	0.18	0.87

TABLE II.

Approximate mileage of principal existing systems. (1952).

	Route Miles.	*Single track Miles.*
Direct Current.		
Conductor Rail 600V	1 600	3 700
Overhead 1 500V	5 600	11 100
Overhead 3 000V	6 200	10 600
Alternating Current.		
Single phase low frequency	10 900	21 200
Unclassified (Chiefly private lines)	7 500	

TABLE V.

Some typical mean substation spacings.

System (and frequency).	Voltage	Railway	Mean spacing. Miles.
Direct Current.	1 500	Central India. Suburban	8
		Main line	12
		Illinois Central	6
		Netherlands	10
		S.N.C.F. Paris-Le Mans *	12
		Paris-Dijon *	9
		Dijon-Lyons	5
		South Africa. Suburban	5
	3 000	Belgian Railway. Brussels-Antwerp	20
		Chicago-Milwaukee-St. Paul	30
		South Africa. Transvaal	9
		Natal	12
Alternating Current. Single phase 16 2/3 cycles.		German Railways. Leipzig	37
		Bavaria	90
	16 000	Sweden	60-90
	15 000	Switzerland	19-31
25 cycles.	11 000	U.S.A. Pennsylvania	8
50 cycles.	16 000	Hungary	20
	25 000	Belgian Congo	22
	25 000	S.N.C.F. project	25

* These electrifications have automatic track sectioning equipments between substations.

TABLE III.

Modern electric locomotive characteristics.

Railway	System	Wheel arrgt.	Date built	No.of motors	Motor voltage	Weight - tons		Driving axle load tons	Max. T.E. lbs.	H.P. hourly rating	H.P. per ton	Max. speed m.p.h.	Annual mileage	Max. adhesive factor %
						Total	Adhesive							
British Railways	660V D.C.	Co.Co.	1948	6 ⌀	400	105	105	17.5	45 000	1 560	14.8	85	75 000	19.1
	1 500V D.C.	Bo.Bo.	1948	4	700	88	88	22	45 000	1 868	21.2	65	—	22.8
South African	3 000V D.C.	Co.Co.	1949	6	1 450	108	108	17.9	57 000	3 700	34.3	55	75 573	23.6
	»	1CoCo1	1953	6	1 450	155	128.5	21.4	73 000	3 250	21	55	75 573	25.3
Norwegian State	15 000V 16 2/3 p.	1Do1.	1949	4	345	81.5	59	14.8		2 080 (kW)		68.5	66 000	—
»	»	Bo.Bo.	1951	4	385	61	61	15.2		1560 (kW)		62.5	66 000	—
Swedish State	15 000V 16 2/3 p.	1C1.	1953	2	383	73.9	44.4	14.8	33 100	2 360	32	62	—	33.3
»	»	Co.Co.	1953	6	415	100.5	100.5	16.7	68 500	4 430	44	59	—	30.4
»	»	Bo.Bo.	1951	4	305	64	64	16.1	35 300	1 730	27	50	—	24.6
Virginian (U.S.A.)	11 000V 25 p.	2 (BoBo + BoBo)	1948	16 ⌀	—	462	462	28.9	162 000 (cont.)	6 800 (cont.)	14.7	50	—	-
Pennsylvania (U.S.A.)	»	2 (CoCo)	1951	12 +	-	325	325	27	182 000	6 000 (cont.)	18.5	63	-	25
»	»	2 (BoBo Bo)	1951	12 +	—	335	335	27.9	187 750	6 000 (cont.)	17.8	63	—	25

- motor-generator control.

+ ignitron control.

TABLE IV.

Modern multiple unit train characteristics.

Railway	System	Year built	Train formation	Empty weight of		Normal loaded weight tons	Adhesive weight tons	Driving axle load tons	Max. T.E. lbs.	H.P. one hour	H.P. per ton		Max. speed m.p.h.	Annual mileage
				Train tons	Motor coach tons						Empty	Loaded		
British Railways	660V D.C. 1 500V D.C.	1951 1949	M.2T.M. M.T.DT.	135 105	40 51	162.2 124	43.4 51	10.85 12.75	19 600 17 200	1 000 840	7.4 8.0	6.2	75 70	70 000 55 500
British Railways (London Underground Lines) ⌀	630V D.C.	1953	8M	272	34	298	150.7	9.42	62 400	2 128	7.8	7.1	60	55 000
Central Indian	1 500V D.C.	1952	M.2T.M.	157.9	40	—	80	10	—	1 400	8.9	—	—	96 000
Danish State	1 500V D.C.	1952	M.2T.M.	168.5			94.4	11.8		1 440	8.5		56	59 000 (average)
South African	3 000V D.C.	1949	M.6T.M.			402	124	15.5	38 400	2 600		6.5	60	57 135
New Haven (U.S.A.) +	11 000V A.C. 25 p. 650V D.C.	under construction	—	—	69.6	—	69.6	17.4	—	400	5.75		80	Not yet ascertained
Pennsylvania (U.S.A.)	11 000V A.C. 25 p.	1950	—	—	61.2	—	33.5	16.75	—	450 (cont).	7.4	—	90	
Norwegian State	15 000V A.C. 16 2/3 p.	1946	—	—	46	—	46	11.5	—	720 (kW)	—	—	74.6	—
Swedish State	15 000V A.C. 16 2/3 p.	1948	M.T.M.	134	—	—	53.2	13.3	16 750	1 360	10	—	84	—

NOTES : M — motor coach.
T — trailer coach.
DT — driving trailer coach.
⌀ — special high acceleration stock for intensive underground service.
\+ — has ignitron-fed D.C. motors.

SECTION A.

QUESTION	*THE RAILWAY EXECUTIVE*	*LONDON TRANSPORT EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
PARTICULARS OF LINES ALREADY ELECTRIFIED OR IN COURSE OF BEING ELECTRIFIED, VIZ :					
1. *Section of lines electrified*	Suburban and in Southern Region some inter-urban lines. Section of main line (in hand)	All lines	Copenhagen suburban lines	Various lines 1911-1950	All main lines and some secondary lines
2. *State system of electrification, type of current, voltage and frequency on contact wire*	Overhead conductor, 1 500 V and D.C. third rail, 660 V D.C.	Third and fourth rail, 630 V D.C.	Overhead conductor, 1 500 V D.C.	Overhead conductor, 15 000 V single phase 16.2/3 cycles	Overhead conductor, 16 000 V single phase 16.2/3 cycles
3. *Route length of electrified section and type of line*	988 miles suburban and main lines	191 miles (suburban)	37 miles (suburban and main lines)	633 miles (State Railways); 25 miles (private railways)	3 660 miles
4. (a) *Actual single track mileage of electrified lines*	2 628 miles	415 miles	62 miles	—	5 680 miles
(b) *Actual single track mileage of traffic lines*	2 394 miles	472 miles	—	2 780 miles	4 120 miles
(c) *Actual single track mileage of sidings*	234 miles	—	11.5 miles	528 miles	1 560 miles
5. *Enumerate special operating difficulties, e.g. steep gradients, curves, tunnels, etc. State number and aggregate length of tunnels*	Southern Region includes 66 tunnels, 20 miles aggregate in route mileage of 721	46 % of single track miles is in tunnel	0.9 miles in tunnel	18-25 ‰ gradient on main lines. 738 tunnels aggregate length 117 miles	None
PASSENGER TRAFFIC ON ELECTRIFIED SECTION					
6. *Train miles per annum worked electrically*	Southern Region (660 V) 39.81×10^6	35.65×10^6	2.19×10^6	5.28×10^6	29.3×10^6
7. (a) *Electric locomotive miles per annum*	225 000	437 000	Nil	2.23×10^6	26.71×10^6
(b) *Electric motor car miles per annum*	239×10^6 Southern Region	215×10^6	4.5×10^6	3.05×10^6	3.9×10^6
FREIGHT TRAFFIC ON ELECTRIFIED SECTION					
9. *Train miles per annum worked electrically*	Included in 6	Not applicable	Not applicable	1.96×10^6	16.9×10^6

QUESTION	*THE RAILWAY EXECUTIVE*	*LONDON TRANSPORT EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
AMOUNT OF ELECTRICITY CONSUMED ANNUALLY FOR ELECTRIC TRACTION					
14. *To be stated as High Tension at point of supply if purchased, or at output of power station if this is owned by railways :*					
(a) *Total consumption for traction, kW. hrs./p.a.*	694 × 10^6	730 × 10^6	45 × 10^6	132 × 10^6 at catenary voltage	1 290 × 10^6
(b) *Maximum half-hour demand aggregated for all supply points, M.W.*	197 M.W. for Southern Region only	174 M.W.	11 M.W. (1/4 hour)	—	167 M.W. (1/4 hour) (From one principal supplier only).
15. **(a) Have you a settled policy to proceed with further electrification?**	No; question under investigation. Individual projects at present considered separately	Yes; system almost completely electrified	Yes, for suburban lines	Yes	Yes
(b) *If so, have you a programme?*	Electrification London/Tilbury/Southend approved in principle.	Programme for additional lines drawn up for London Planning Working Party not yet approved by Ministry of Transport	Electrification of existing lines will be continued if traffic requires it and new lines built if road traffic increases too much	900 miles.	Yes; at the rate of 85 miles per annum for five years ahead
(c) *If so, at what rate in route miles per year, and for how long?*	Other schemes including extension of Southern Region electrification under consideration			62 miles per year.	
16. (a) **Have you a settled programme to use other means of haulage as opposed to electrification?**	No	No	No; a Committee is studying what system of traction should be used on main lines	No	No; but diesel operation would be considered for low traffic density lines if a diesel locomotive with the low permissible axle loads becomes available
(b) *If so, why?*					
17. **Was the electrification of any of the above lines undertaken, or is a projected electrification proposed, mainly for any one or more of the following reasons, and if so for which of them in each case :**					
(a) *To utilise hydro-electric power, or because of high cost of coal or of oil?*	According to the line involved, some or all of the factors have operated	Reasons (b) to (g) inclusive had an important bearing on the decision to electrify, but electric traction is essential for the operation of deep level tube railways	To increase the capacity of suburban lines	For all the reasons mentioned	(a) and (b). Yes
(b) *To increase line capacity?*					
(c) *To overcome congestion at terminals?*					(c), (d) and (e). No
(d) *To abate smoke nuisance in either towns or tunnels?*					

QUESTION	*THE RAILWAY EXECUTIVE*	*LONDON TRANSPORT EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
17. *(Continued)* (e) *To give improved performance on steep gradients?* (f) *In anticipation of obtaining increased traffic?* (g) *To reduce running expenses?* (h) *For reasons affecting national politics?* (i) *Because of considerations affecting national economics, e.g. to reduce manpower?* (j) *For any other special reasons?*					(f) Yes (g) Yes. The principal and conclusive reason (h) and (i). Yes, to a certain extent (j) No
18. (a) **State one or more of the main reasons which governed the choice of system at the time the choice was made** (b) *With the knowledge now available and under today's conditions would these reasons still be valid?* (c) *If not, which of them no longer apply, and why?* (d) *What system would you choose today, and why?*	(a) to (d) - D.C. systems were chosen because of improved reliability of D.C. equipment in comparison with the high cost of alternating current train equipment and its unsuitability for heavy suburban services involving frequent starting and stopping. Higher voltage D.C. overhead systems were subsequently chosen mainly to reduce overall costs. General electrification would be on the 1 500V D.C. overhead line system, the conductor rail system being retained on certain parts of the Southern Region. 3 000V D.C. or single phase alternating current at low or standard frequency might be used for secondary lines with light traffic, provided this would not be prejudicial to operation on adjacent lines equipped at 1 500V	Freedom from electrolysis was an important factor in the decision to use the third and fourth rail system and permits of the running rails being used solely for signalling, thus allowing the adoption of simple track circuits. This simplifies testing and installation, particularly in the deep tunnels with their heavy traffic. A single damaged insulator or a fault between one pole and earth on a single train does not dislocate traffic. This is of major importance on a system with few facilities for diverting trains from one underground route to another. These reasons are still considered valid and it is proposed to retain the fourth rail fully insulated system	The D.C. system is specially suited to suburban traffic and will be retained	Single phase high tension considered to be the most suitable	D.C. operation was not considered suitable in view of the great long distances and relatively light traffic on the majority of lines. 50 cycle locomotive motors not being available, the main question was whether to generate low frequency current in railway owned power stations or use the existing 50 cycle power network. The main power source being hydro-electric in the north of the country, involving in any case long transmission lines, pointed to the use of a common transmission system for railways and industry as the more economical solution, and the use of synchronous motor generators for conversion in the substations brought additional advantages in improving voltage regulation and permitting the supply of reactive power to the network. These reasons are still considered valid and the commitment to single phase 16.2/3 cycles is so heavy that other systems have received little attention hitherto

QUESTION	*THE RAILWAY EXECUTIVE*	*LONDON TRANSPORT EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
19. (a) **If you were not influenced by considerations of interrunning with existing electrified lines of your own, or neighbouring railways, and could neglect the cost of re-equipping your existing electrified lines, would you change the system now in use, and to what other system?** (b) *If so, what consideration mainly prevents you from doing so?*	(a) and (b) - If it were not for the considerations mentioned in the question, attention would be given to the use of 3 000V or A.C. 50 cycle systems, but it is considered that any economy remaining after subtracting the cost of obtaining bigger clearances for the latter system would not make the change of system worth while. The D.C. systems are considered particularly suitable for the relatively short and complicated lines of heavy traffic which are expected eventually to be electrified to improve the quality of railway service and reduce running costs	No.	No particulars.	As far as we know the systems today we would not change	No.

SECTION B.

QUESTION	*THE RAILWAY EXECUTIVE*	*LONDON TRANSPORT EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
POWER SUPPLY					
1. (a) *Do you own the power stations — entirely?*	Two power stations are still railway-owned, but the larger part of the current is purchased	Yes	No	No, with one small exception	No
(b) *Do you own the power stations — in part?*	No	Not applicable	No	No	No
2. (a) *Do you buy power?* (b) *If so, at which voltage and frequency, and number of phases?*	Yes Usually at standard 50 cycle frequency at 11 or 33 kV Part of the Southern Region system was supplied at 25 cycles and is in the process of being converted to 50 cycles	Yes 11 kV, 50 cycles, 3 phases	Yes 10 or 30 kV A.C. 50 cycles 3 phases	Yes 16.2/3 cycles at 55 kV, 1 phase 50 cycles, 3 phases at 45 and 60 kV	Yes 6.3 kV 50 cycles, 3 phases

QUESTION	*THE RAILWAY EXECUTIVE*	*LONDON TRANSPORT EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
3. *What factors controlled your choice among the above alternatives?*	The determining factor was originally economy	82% of the power used is supplied from railway-owned stations which is preferred for the following reasons : (i) Economic advantage. (ii) Increased reliability for electric power supplies owing to freedom from disturbances originating from outside the system	Economic	Local	The transformers for stepping down the voltage to 6 kV are the property of the power supply which enable them to be utilised to better advantage whilst at the same time a reduction can be made in spare plant capacity
5. (a) *Are high voltage feeders necessary to transmit power to substations, and if so, do you own them entirely, or in part?*	In general, yes; and in general, entirely railway-owned	Yes, entirely railway-owned	Yes, entirely railway-owned	Yes, part owners of single phase distribution at 76 and 55 kV	In general, no; substations being sited where power is taken from the supply network
(b) *State type and length of feeders and how they are arranged*	The feeders are generally arranged in cable	Cable feeders, two or more radial feeders to each substation. Total number : 277; average length : 3.2/3.8 miles	Cables placed along the track, but all future cables will be placed in roads to decrease corrosion	Overhead lines	
(c) *Are feeders used to supply power to consumers outside your own railway, and if so, state how it affects your railway technically and commercially*	In general, no ; but on some parts of the railway supplies for ancillary services are given from traction substations	There is a supplementary cable network for supplies to depots, garages, etc.	No	No	
7. (a) *If you buy power, state tariff as fully as possible as at January 1, 1953, and how price is restricted by law. How does the price compare with that charged for industrial supplies?* *In particular, state : —*	A new scheme of charging under consideration by Ministry of Transport and Ministry of Fuel & Power arising from 1947 Acts of Parliament. Costs vary considerably from one section to another. Mostly on two-part tariff with charge per 1/2-hour maximum demand varying from £3.7.6 to £4.5.6; unit charge varying from .207 to .44d. per unit with fuel adjustment charge varying from .0007 to .00085d. per unit per penny per ton difference in the basic price of coal, varying from 14/6d. to 38/- per ton. In addition, charges are made for transmission losses and service charges for supply equipmen	No particulars	35 kroner per annum per kW. 1/4-hour demand, plus .026 kroner per kWh, plus .00125 kroner for each kroner that the price of coal exceeds 20 kroner per ton	Differing tariffs mean price: 2.94 ore/kWh at 15 000 V single phase	The following particulars relate to the purchase of 167 M. W; 919 × 10^6 kWh from the main supplier, viz., a fixed annual charge of 670 000 crowns. A charge of 45 crowns per kW per year is based on the mean value of the 1/4-hour demand for the four highest 24-hour demand periods during the year, subject to rebate mentioned in 7 (b) below, plus an energy charge varying from 0.7 to 1.0 ore per kWh, plus a supplement varying with the cost of living index which amounted to 45% in 1952. These prices are more favourable than the charge for the industrial load of similar magnitude

QUESTION	*THE RAILWAY EXECUTIVE*	*LONDON TRANSPORT EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
7. *(Continued).*					
(b) *Can you buy power « off peak » at specially preferential terms?*	No	No	No	No	No, but a rebate of 8 000 kW is allowed
(c) *If you take a lagging wattless current or cause unbalance, are you penalised for doing so, and how?*	Varies; penalty is sometimes imposed below 0.85 p.f.	No	No	No	No
(d) *If you can supply leading wattless current or regenerated power, on what terms can you sell it to the Supply Authority?*	No	Not applicable	Not applicable	Some: no bonus	Allowance has been made for leading wattless current normally supplied to the network in the above tariff
(e) *Do you have to make any direct contribution by capital payment or by rent to the capital cost incurred by the Supply Authority in giving your supply?*	Yes; see service charge above	Not applicable	Yes; by the M.D. charge mentioned in (a)	No	No
(f) *Does your maximum demand for power coincide with the national maximum demand?*	In general, no	Yes	Yes	Demand is about 1 % of total demand	No
8. *What restrictions are placed on you with regard to :*					
(a) *Interference with wave form of supply?*	No particular restriction	None	None	None	None
(b) *Power factor?*	Minimum 0.85 to 0.9	None	None	None	None
(c) *Negative phase sequence currents?*	None	None	None	None	None

SECTION C.

QUESTION	*THE RAILWAY EXECUTIVE*	*LONDON TRANSPORT EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
OVERHEAD LINE AND FIXED TRACK EQUIPMENT					
GENERAL					
1. *For what voltage drop do you design the train equipments :*					
(a) *Normal*	Generally 10 %	8.75 %	Normal less than 25 %	4 500V from substation voltage of 16 500	25 %
(b) *Emergency*	25 % to 50 %	28.5 %	Up to 30 %	6 500	15 % lower voltage than (a)
(c) *Do you allow large drops on branch lines? If so, by how much?*	No	No	No	6 500	No

QUESTION	*THE RAILWAY EXECUTIVE*	*LONDON TRANSPORT EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
2. (a) *Do you restrict the maximum potential between running rails and earth?*	In general, no	No	Normally less than 75 V	—	No
(b) *To what extent is electrolytic damage experienced? State costs, if any*	In general, very little	None	Only to a small extent and only in special cases; repairs have cost less than 10 000 Kr. during 18 years		None has been verified
3. (a) *What is the theoretically correct spacing of substations?*	Depends on system and type of traffic; on third rail systems from 3 1/2 to 5 1/2 miles with an average of 4 miles; 1 500 V systems the average of existing systems is approx. 4.7 miles and the maximum 6	(a) Varies from .46 of a mile to 4.42 miles	(a) Average about 6 miles	(a) —	No information available
(b) *What is actual average distance apart of substations?*		(b) 1.73 miles	—	(b) 44 miles	
(c) *What is actual maximum distance apart of substations?*		(c) 4.42 miles	—	(c) 62 miles	
4. *What is total number of substations?*	1 500 V D.C. 19 built or in construction; 660 V Southern Region 159	87	5 to be increased to 8 during 1953	15	No particulars
5. *Are intermediate switching or paralleling stations placed between substations?*	Generally, yes	No	No	No	No
6. (a) *Are open wire telecommunication circuits altered, e.g. cabled after lines are electrified? If so, why?*	3rd rail systems: no. Overhead systems : generally yes, to obtain clearance and for fear of interference	Open wire telecommunication circuits are not used	Cables, because open wires would be too close to the overhead line	Cabled, to minimise disturbances	Yes, to avoid noise and high induced voltage
(b) *If so, are costs charged against cost of electrification?*	Generally charged against the cost of electrification		No	Yes	The cabling of the circuits reduces their maintenance cost and increases reliability and above 10 pairs a financial advantage results, irrespective of electrification

QUESTION	*THE RAILWAY EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
OVERHEAD LINE				
8. *What is material, size and arrangement of overhead contact system :*				
(a) *Main lines?*	.75 sq. in. copper main and auxiliary catenary and cadmium copper contact wire	(a) and (b) Contact wires are copper, single and double 100 mm², the former with 50 and the latter with 70 mm² bronze catenaries	(a) Contact wire copper : 100 mm² Catenary copper : 50 mm²	(a) Contact wire copper : 80 or 100 mm²; catenary copper : 50 mm²
(b) *Branch lines?*	—	Supplementary wires of 95, 150 or 240 mm²	—	Return wire (copper aluminium) : 130 mm²
(c) *Sidings?*	.36 sq. in. copper equivalent cadmium copper catenary and contact wire	(c) 100 mm² contact wire, 50 mm² catenary	—	
9. *What types of construction are used for the supports :*				
(a) *Single track,* (b) *Two track,* (c) *Multiple track : State also for main lines, branch lines and sidings where the construction differs*	(a) to (c) Portal type structures used when possible, built of broad flanged beams with double channel lattice or interspan structures above four tracks	(a) and (b) Brackets, supported on poles (c) Cross suspension	Bracket arms on pin insulators on wood poles (b) As above for each track (c) Suspended on cross bars. Branch lines and sidings as above	Brackets supported on and insulated at lattice poles (b) and (c) Portal type with pull rods, tubes and struts
(d) *Have you provided mechanical and electrical independence of tracks? If so, how has it been obtained, particularly at junctions?*	(d) In general, yes, except at junctions	(d) Yes, but not in stations	(d) Electrical	(d) No
10. *What is the average distance apart of structures on tangent track?*	Present maximum span on tangent track: 210 ft	40-70 metres	50 yards	Normal distance: 66 yards, reduced to 54 yards in exposed areas and mountainous districts
11. *What is the normal height and minimum height of wires above rail :*				
(a) *in open track?*	(a) 16 ft. normal, 13 ft. 5 ins. min.	(a) 5.5 metres	(a) 5.5 m normal	
(b) *at level crossings?*	(b) 18 ft. at public crossings, 16 ft. at farm crossings	(b) Do not exist	(b) 4.8 m minimum	5.6 m normal 5.0 m minimum
(c) *in stations?*	(c) As (a)	(c) 5.5 metres	(c) 4.8 m	
(d) *in tunnels?*	(d) As (a)	(d) 4.8 metres	(d) 4.8 m normal 4.8 m minimum	

QUESTION	*THE RAILWAY EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
12. (a) *What are the average and the minimum permitted clearances between live metal and earthed metal or other structures?*	4 ins. minimum 6 ins. normal	(a) and (b) 150 mm	(a) 250 mm average 200 mm minim.	(a) 250 mm minim. 400 mm normal
(b) *between minimum height of contact wire and clearance gauge of rolling stock?*	(b) As (a)		(b) Rolling stock gauge: 4.3 m	(b) 350 mm
13. *Are these clearances increased in special circumstances? e.g. in tunnels, through which steam locomotives pass, and by how much?*	Yes, if possible	No	No	No
14. *What measures have been taken to ensure the safety of the enginemen of steam locomotives running on tracks provided with overhead contact wires, specially as regards the handling of long fire tools or the prohibition from climbing on to the higher parts of locomotives and tenders?*	20 ft. wire height is used in certain terminals and sidings and use of fire irons when climbing on high parts of engines prohibited	Suitable warnings have been placed on steam locomotives	All ladders and footboards more than 2 m above rail level provided with warning signs. No-one may approach closer than 1 m from live metal	Directions have been issued and caution boards placed on locomotives and tenders
15. (a) *Have these clearances in Questions C. 12, 13 and 14 been effective?*	Yes	A few accidents have taken place on steam locomotives	Yes	Sufficient on the whole
(b) *Would you propose to increase or reduce them for future work?*	Reduce minimum	No	No	No
(c) *Would State legislation be necessary to allow you to reduce them?*	Consent of the Ministry of Transport would be necessary	Yes	Yes	Settled by State Railways Board in close collaboration with State Electrical Inspectorate
16. *State any experience you have of prestressed concrete structures*	None	None, but a line is now being equipped using them	None	Susceptibility to damage is considerably greater for concrete masts than for iron masts. Concrete masts are much more difficult to handle and to repair. Prestressed concrete masts are not employed on new electrifications
17. *To what extent is your choice of structure determined by availability of materials?*	Economy rather than availability determines the choice	No reply	Wood and concrete available, so we use them	Prestressed concrete masts were introduced on a 172 mile section during the war owing to shortage of steel

QUESTION	*THE RAILWAY EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
19. *What provision do you make for avoiding damage from atmospheric disturbances, e.g. lightning stroke?*	4 m.f. capacitors between line and earth at substation end of each section	Capacitors on all outgoing 1 500 V feeders	Lightning arrestors in all substations	None
20. (a) *Cost per single track mile erected on level tangent double main line tracks, assuming no special site difficulties and that a substantial scheme is in hand :*				
(i) *including provision of foundations*	£ 6 800	80 000 kroner per single track km	No double track experience in past 14 years	67 500 crowns per mile
(ii) *excluding provision of foundations*	£ 5 400	60 000 kroner per single track km		60 000 crowns per mile
(b) *Actual total cost of overhead equipment per single track mile, adjusted to January 1, 1953 prices, of an actual electrified section of line, including all its special work at junctions, sidings, stations, tunnels, etc. :*	Figures given below relate to a complicated suburban section of line			
(i) *including provision of foundations*	£ 12 800		(i) 64 500 kroner per mile	88 000 crowns per mile
(ii) *excluding provision of foundations*	£ 10 000		(ii) 60 600 kroner per mile	75 000 crowns per mile (all exclusive of auxiliary line)
21. *Do you do this work by your own labour or do you employ contractors for it?*	Installation has so far been carried out by contractors	Foundations are carried out by contractors; erection of poles and wire by our own labour	Own labour	Own labour
22. (a) *What were the corresponding costs for the actual scheme of altering structures, etc., to obtain the necessary clearances?*	Costs for obtaining clearances for Liverpool Street-Shenfield electrification (99 single track miles) £ 178 600	Special measures have only been necessary in a very small degree	8 800 kroner per single track mile	Varies greatly according to character of line. About 10 % of the value indicated in the reply to question 20 (b) (i) was for this work
(b) *Would these costs have been materially increased or decreased if a different system (involving larger or smaller clearances) had been adopted?*	Would vary with clearances required and nature of line			Yes, but not very much
(c) *If so, by how much, approximately?*				

QUESTION	*THE RAILWAY EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
3. *Have you had complaints of interference with either :*	(a) to (d) No	(a) to (d) No		(a) Yes; special precautions are to be taken when track circuits are constructed
(a) *signals ?*			(a) No	
(b) *telecommunication circuits ?*			(b) No	(b) Yes. Return feeders with booster transformer telecommunication circuits in cable
(c) *radio ?*			(c) Yes, in icy weather, no remedy yet found	(c) Yes, especially when there is ice coating on conductor wire. Investigations are going on
(d) *television ?*			(d) No experience	(d) No experience
In each case, what complaints have been received, and how have they been overcome ?				(e) Return feeder with booster transformer is prescribed. The Railways are directed to contribute to the elimination of interference according to the technical possibilities
(e) *What restrictions are placed on you by State legislation in regard to these matters ?*			(e) Construction controlled by State Regulations	
4. *State frequency of failures of overhead equipment, expressed as :*				
(a) *Number of failures per single track mile equipped per year*	(a) to (b) No reliable statistics yet	(a) One per year per 62 single track miles	(a) 0.3 failures : 1951/52 per year per S.T.M.	(a) Six disturbances of 3 1/2 minutes or more per year per 100 single track miles
(b) *Availability for use, giving definition of availability used*		(b) The failures had no influence upon the traffic	(b) An average of 43 miles concerned in each failure Total duration : 9 556 minutes in the year	(b) No statistics yet available, but a modified statistical system is under consideration to take into account the fact that different disturbances exercise a varying influence on the traffic. A term that might be employed is the number of train minutes during which the disturbance has taken place.
5. *State the measures taken to guard against danger from a sagging or broken wire*	No special precautions	The distances between the contact wire hangers are so short at the platforms that broken wire cannot cause any danger	All the taller structures in neighbourhood of live metal connected to running rails	None

QUESTION	*THE RAILWAY EXECUTIVE*	*LONDON TRANSPORT EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
SUBSTATIONS					
26. *What type and size of equipment is installed in substations, and specify any features to which you attach importance*	In general 2.0 and 2.5 M.W. Mercury Arc Rectifiers. Pumpless steel or glass bulb preferred	Aggregate capacity: Rotary Converters 198 M.W. Rectifiers 176 M.W. Rotary converters are being replaced by 1.0, 1.5 or 2.0 M.W. pumpless steel or glass bulb rectifiers	Water or air cooled rectifiers: 1 500 amps, 1 650 V continuous. 3 000 amps for 2 minutes 4 500 amps for 40 seconds	2 or 3 transformers of 215 M.V.A. and in converter substations 1 or 2 converters of 4 M.V.A.	Motor generators 2.9 and 5.8 M.V.A.
27. (a) *Is the converting equipment suitable for regenerative electric braking?*	In general, no; but regenerative resistances are being installed on the Manchester - Sheffield - Wath electrification	No	No	Yes	No
(b) *Is it used for this purpose?*				No	
28. (a) *Are filter circuits installed?*	(a) In general, no, with third rail electrification, but on overhead electrification they have been installed to reduce interference, on a few open wire telephone lines, paralleling electrified lines still in service	In some cases yes, but in many cases they have been taken out of service without complaint	Yes	No	No
(b) *What benefit has been derived from them?*			Disturbance to telephones, radios and telegraphs avoided		
29. *Give actual total cost of substation equipment adjusted to January 1, 1953 price levels for the actual section of electrified line used in question C. 24 above*	The figures given below relate to the Shenfield electrification, comprising 7 33 kV substations and 15 2 000 kW rectifiers				
(a) *excluding cost of building work*	£ 444 300	Not available	(a) For 2 rectifier substations 1 400 000 kroner	(a) $45 \cdot 10^6$ kroner Substation with 2 converters	1.5×10^6 crowns
(b) *including cost of building work*	£ 594 200		(b) 1 650 000 kroner	(b) 6.5×10^6 kroner Substation with 2 converters	2×10^6 crowns

QUESTION	*THE RAILWAY EXECUTIVE*	*LONDON TRANSPORT EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
32. (a) *Are substations attended?*	In general, no	(a) 42 substations are manually controlled	One attended, remainder semi-automatic or remote controlled	Yes, most	Yes
(b) *Are substations and/or intermediate stations remotely controlled, and by what method?*	In general, yes; by telephone type supervisory equipment	(b) 48 substations are remote controlled, 23 by direct wire, 24 by supervisory control, 1 automatic with time switch		No	Remote control, using register selector system, and voice frequency transmission is planned

SECTION D.

QUESTION	*THE RAILWAY EXECUTIVE*	*LONDON TRANSPORT EXECUTIVE*	*DANISH STATE RAILWAYS*	*NORWEGIAN STATE RAILWAYS*	*SWEDISH STATE RAILWAYS*
MOTIVE POWER UNITS					
1-12. *See tables III and IV.*					
13. *What arrangements are made for heating passenger trains?*	Seven 400 W heaters in series on 1 500 V multiple unit stock Electrically heated steam boilers are being installed on locomotives	Electric heaters at line voltage	Twelve electric heaters in series on 1 500 V	800/1 000 V heating circuit	Electric heaters supplied at 6, 8 or 1 000 V from train bus line, fed by 500 amp transformer on locomotive
19. (a) *What is normal driving crew in passenger service?*	(a) Locomotives: Driver and Fireman on running lines	—	—	(a) One man	(a) : Express trains : one Driver and one Attendant Passenger trains: one Driver
(b) *What is normal driving crew in freight service?*	(b) As (a)			(b) One or two men	(b) Through freight trains : one Driver and one Attendant It should be noted that there is normally no other crew on train
(c) *What is normal driving crew of motor cars?*	(c) One Motorman	One Driver	One Driver	(c) One man	(c) : Express trains : one Driver and one Attendant Local trains : one Driver
22. (a) *State annual mileage per motor car*	50 000 to 70 000 miles	55 000 miles	56 000 to 62 000 miles	105 000 km	No particulars
(b) *State annual mileage per locomotive*	75 000 miles			107 000 km	

SECTION A.

QUESTION	*SOUTH AFRICAN RAILWAYS*	*CENTRAL INDIAN RAILWAYS*	*SOUTHERN INDIAN RAILWAYS*	*ASSOCIATION OF AMERICAN RAILROADS*
PARTICULARS OF LINES ALREADY ELECTRIFIED OR IN COURSE OF BEING ELECTRIFIED, VIZ :				
1. *Section of lines electrified*	Capetown suburban lines : 1928 Transvaal interurban lines 1937 onwards Natal main lines 1926 onwards	Bombay suburban lines : 1925 Main lines : 1926 onwards	Madras Tambaram 1931	Suburban, main and freight lines chiefly between 1905 and 1930
2. *State system of electrification; type of current, voltage and frequency on contact wire*	Overhead conductor : 3 000 V D.C. Overhead conductor : 1 500 V D.C. Capetown only in process of conversion to 3 000 V	Overhead conductor : 1 500 V D.C.	Overhead conductor : 1 500 V D.C.	Principally overhead conductor : 1 500 V to 3 000 V D.C. Overhead conductor : 11 000 V Single phase : 25 cycles
3. *Route length of electrified section and type of line*	1 500 V D.C. . 49 miles (suburban) 3 000 V D.C. : 635 miles (main and suburban) Total : 684 miles	185 miles (suburban and main line)	18 miles (suburban)	2 567 miles Class I lines in operation 1950
4. (a) *Actual single track mileage of electrified lines*	1 388 miles	582 miles	41 miles	6 125 miles
(b) *Actual single track mileage of traffic lines*	1 035 miles	430 miles	36 miles	5 012 miles
(c) *Actual single track mileage of sidings*	353 miles	152 miles	5 miles	1 014 miles
5. *Enumerate special operating difficulties, e.g. steep gradients, curves, tunnels, etc. State number and aggregate length of tunnels*	21 tunnels on Natal lines 5.7 miles total length	48 tunnels, aggregating 6.7 miles. Ruling grades of 1 in 37	None	There are 66 tunnels, aggregating 22 miles and ruling grades up to 2.2 % on Virginian, Chicago, Milwaukee, St. Paul and Pacific, and Great Northern, the three principal electrified lines
PASSENGER TRAFFIC ON ELECTRIFIED SECTION				
6. *Train miles per annum worked electrically*	9.43×10^6	1.89×10^6 by locomotives 4.95×10^6 by multiple units, in terms of single units	53 000 by locomotives 1.16×10^6 by multiple units	18.4×10^6 by locomotives; multiple units not available

QUESTION	*SOUTH AFRICAN RAILWAYS*	*CENTRAL INDIAN RAILWAYS*	*SOUTHERN INDIAN RAILWAYS*	*ASSOCIATION OF AMERICAN RAILROADS*
7. (a) *Electric locomotive miles per annum*	16.2 × 10^6	2.3 × 10^6	55 000	19.4 × 10^6
(b) *Electric motor car miles per annum*	15.3 × 10^6	5.0 × 10^6	1.5 × 10^6	Not available
FREIGHT TRAFFIC ON ELECTRIFIED SECTION				
9. *Train miles per annum worked electrically*	6.1 × 10^6	850 000	59 000	8.1 × 10^6
AMOUNT OF ELECTRICITY CONSUMED ANNUALLY FOR ELECTRIC TRACTION				
14. *To be stated as High Tension at point of supply if purchased, or at output of power station if this is owned by railways*				1 163 by locomotives 607 by motor cars
(a) *Total consumption for traction, kW.hrs./p.a.*	546 × 10^6	179 × 10^6	10 × 10^6	2 260 × 10^6
(b) *Maximum half-hour demand aggregated for all supply points, M.W.*	Not available	37 M.W.	2.6 M.W.	Not available
15. (a) **Have you a settled policy to proceed with further electrification?**	Each proposal considered on its merits	Under consideration Each scheme to be financially justified; policy is to conserve high grade coals	No	(a) Electrification expansion in the U.S.A. is now in dormant state
(b) *If so, have you a programme?*	No	No	No	(b) — do —
(c) *If so, at what rate in route miles per year, and for how long?*				(c) — do —
16. (a) **Have you a settled programme to use other means of haulage as opposed to electrification?** (b) *If so, why?*	Yes, in flat country steam haulage mainly because coal for steam locomotives is produced locally	Yes; there is a settled programme for steam locomotives : electrification of the major part of the lines cannot be financially justified until cheap electric power is available. Diesel traction only considered where water and power are scarce	No	The trend is definitely towards the use of diesel electric locomotives; application of gas turbine locomotives also being explored

QUESTION	*SOUTH AFRICAN RAILWAYS*	*CENTRAL INDIAN RAILWAYS*	*SOUTHERN INDIAN RAILWAYS*	*ASSOCIATION OF AMERICAN RAILROADS*
17. **Was the electrification of any of the above lines undertaken, or is a projected electrification proposed, mainly for any one or more of the following reasons and if so for which of them in each case :** (a) *To utilise hydro-electric power, or because of high cost of coal or of oil?* (b) *To increase line capacity?* (c) *To overcome congestion at terminals?* (d) *To abate smoke nuisance in either towns or tunnels?* (e) *To give improved performance on steep gradients?* (f) *In anticipation of obtaining increased traffic?* (g) *To reduce running expenses?* (h) *For reasons affecting national politics?* (i) *Because of considerations affecting national economics, e.g. to reduce manpower?* (j) *For any other special reasons?*	No (b) to (g) inclusive Yes, particularly (b) (c), (e) and (g)	(b) to (g) Yes Financial results satisfactory and up to expectation. Extension of electrification from Igapitura to Bhusavol (192 miles double track) is projected in respect of reasons such as (b), (c) and (j) and to conserve high grade coal as a national economy by the use of low grade coal in Kalyan Power Station	The electrification of Madras suburban lines was to develop the suburbs, relieve overcrowding in the city by a faster and frequent train service Additional advantages were expected from increased traffic and reduction in running expenses inter alia by obviating the use of high priced coal	In general, the Great Northern, the Milwaukee and the Virginian electrification were mainly to obtain improved performance on lines of heavy grade and curvature with smoke abatement in the tunnels. The New York City lines were electrified to abate smoke nuisance and to increase capacity of lines and terminals. The same factors influenced the Pennsylvanian and Reading in Philadelphia. Pennsylvania Main line electrification from New York to Washington with the westward leg from Philadelphia to Harrisburg was primarily to increase line capacity, to give increased performance and to reduce running expenses
18. (a) **State one or more of the main reasons which governed the choice of system at the time the choice was made** (b) *With the knowledge now available and under today's conditions would these reasons still be valid?* (c) *If not, which of them no longer apply, and why?* (d) *What system would you choose today, and why?*	3 000 V D.C. chosen on account of long distance involved and its relative simplicity and efficient operation. 1 500 V was considered more suitable for suburban motor coach service at the time. The successful use of 3 000 V mercury arc rectifiers justifies this view and suburban lines will be converted to 3 000 V and this system will be standardised in view of the extent of the existing electrification on this system and the good results obtained	In 1922 the 1 500 V system was considered most suitable for a suburban electrification on account of the performance characteristics of D.C. series motors, but this reason is not still considered valid as the successful modern design of A.C. for direct operating on industrial frequencies is the main reason why D.C. should not be perpetuated. If the experiments now being carried out in France and Germany on H.V. single phase industrial frequency are successful, it may be possible to electrify even lower density traffic lines economically	The 1 500 V system was considered the most suitable and had already been adopted on other railways in West India. This system is still considered suitable	—

QUESTION	*SOUTH AFRICAN RAILWAYS*	*CENTRAL INDIAN RAILWAYS*	*SOUTHERN INDIAN RAILWAYS*	*ASSOCIATION OF AMERICAN RAILROADS*
9. (a) **If you were not influenced by considerations of interrunning with existing electrified lines of your own, or neighbouring railways, and could neglect the cost of re-equipping your existing electrified lines, would you change the system now in use, and to what other system?**	No	Yes. 11 or 22 kV 50 cycle A.C. single phase	No	Not a factor due to small amount of electrification activity and trend towards use of Diesel Electric Motive Power
(b) *If so, what consideration mainly prevents you from doing so?*		The additional costs that would be incurred during the changeover as traffic movements may not be interrupted		

SECTION B.

QUESTION	*SOUTH AFRICAN RAILWAYS*	*CENTRAL INDIAN RAILWAYS*	*SOUTHERN INDIAN RAILWAYS*	*ASSOCIATION OF AMERICAN RAILROADS*
POWER SUPPLY				
1. (a) *Do you own the power stations — entirely?*	No	One power station is railway-owned	No	The general practice is to purchase power but several railways generate substantial amounts
(b) *Do you own the power stations — in part?*	No	Up to now, power is being purchased from Tata at 22 kV, single phase A.C. 50 cycles for feeding suburban section	No	
2. (a) *Do you buy power?*	Yes	No, but power is interchanged between the railway power station and Tata high voltage system which are inter-connected at 95 kV, since 1940	Yes	Yes
(b) *If so, at what voltage and frequency, and number of phases?*	At various voltages from 10 to 88 kV, 50 cycles 3-phases	—	5 kV, 50 cycles, 3-phases	Usually 3-phase, 60 cycles at 13.2 to 13.8 kV
3. *What factors controlled your choice among the above alternatives?*	Choice governed by economics and the availability of E.H.T. distribution provided by the Supply Authority	The power station at Kalyan was built for the main line electrification scheme so as to have an independent supply as the Tata hydro-electric supply could not be guaranteed due to vagaries of the monsoon	Availability of power on satisfactory terms	Economic factors

QUESTION	SOUTH [illegible] RAILWAYS	CENTRAL INDIAN RAILWAYS	SOUTHERN INDIAN RAILWAYS	ASSOCIATION OF AMERICAN RAILROADS
[illegible]	Yes: owned by Supply Authority	Yes: feeders are mostly owned by the Railways	Yes, entirely railway-owned	Yes, generally railway-owned
[illegible]	3-wire overhead transmission lines, partly on track structures, partly over routes away from the railway with some underground cables in suburban areas	22 kV cables, 22 and 95 kV overhead lines	33 kV overhead lines	Varies widely
(c) *Are feeders used to supply current to consumers outside your railway, and if so, state how it affects your railway technical and commercial?*	Certain lines are used to supply other consumers	Yes, local supplies are given from certain substations	No	Generally, no
[illegible] *restricted by law. How does the price compare with that charged for industrial supplies?* *In particular, what —*	Chiefly two-part tariffs, M.D. and unit charges : Cape suburban : all-in average cost per unit of .6611d. in 1952 Natal: all-in cost per unit in 1952, .4455d. based on a two-part tariff Transvaal: flat rate .4408d. per unit plus a coal clause less a discount. The price to be charged is controlled by law - Section 10 of Act No. 42 of 1922 Some of the tariffs are at present under consideration	Do not buy power, but any excess energy consumed by the Railways is returned to Tata's hydro-electric system in kWh, to whom an annual rental is paid for the use of their transmission lines	Unit charge varies from .35 to .5 annas per unit per month with an additional rate for maximum demand varying from 2.8 to 4 - per kVA, all subject to coal clause	Power costs about 1.0 cent per kWh
(b) *Can you buy power "off peak" at specially preferential terms?*	No		No	Generally, no
(c) *If you take a lagging wattless current or cause unbalance, are you penalised for doing so, and how?*	Not applicable	No	No	Usually there is a minimum power factor clause
(d) *If you can supply leading wattless current or regenerated power, on what terms can you sell it to the Supply Authority?*	Allowance is made for regenerated energy at the full rate			Regenerated power is usually credited in full
(e) *Do you have to make any direct contribution by capital payment or by rent to the capital cost incurred by the Supply Authority in giving your supply?*	Yes - through the tariff	Yes - rent charge, see (a) above	No	Usually covered by a demand charge in the tariff
(f) *Does your maximum demand for power coincide with the nations' maximum demand?*	Not known	Coincides with Tata's	No	Not available

QUESTION	*SOUTH AFRICAN RAILWAYS*	*CENTRAL INDIAN RAILWAYS*	*SOUTHERN INDIAN RAILWAYS*	*ASSOCIATION OF AMERICAN RAILROADS*
8. *What restrictions are placed on you with regard to :*				
(a) *Interference with wave form of supply?*	No restrictions, but precautions are taken for all substations to reduce interference with communication lines. A special Committee exists which deals with any special problems which may arise	None	None	None, except a minimum power factor clause in the contract
(b) *Power factor?*		None	None	
(c) *Negative phase sequence currents?*		None	None	

SECTION C.

QUESTION	*SOUTH AFRICAN RAILWAYS*	*CENTRAL INDIAN RAILWAYS*	*SOUTHERN INDIAN RAILWAYS*	*ASSOCIATION OF AMERICAN RAILROADS*
OVERHEAD LINE AND FIXED TRACK EQUIPMENT				
GENERAL				
1. *For what voltage drop do you design the train equipments :*				
(a) *Normal*	2 900 V	100 V	27 %	A.C. systems 10 %, D.C. 20 %
(b) *Emergency*	2 700 V to 3 600 V	800 V	45 %	A.C. system 25 %, D.C. 50 %
(c) *Do you allow large drops on branch lines? If so, by how much?*	No	300 V	No	Not electrified
2. (a) *Do you restrict the maximum potential between running rails and earth?*	Restricted to 40 V as far as possible	No	Yes	Yes, on some railways
(b) *To what extent is electrolytic damage experienced? State costs, if any*	Occasionally only	Nil	Nil	Costs not available
3. (a) *What is the theoretically correct spacing of substations?* (b) *What is actual average distance apart of substations?* (c) *What is actual maximum distance apart of substations?*	The average distance is 5 miles for the 1 500 V suburban, and 9 to 12 miles for 3 000 V system	Average spacing; suburban 8 miles. Main line 12 miles. Maximum spacing; suburban 13 miles, main line 15 miles	(a) to (c) : 9.2 miles	2 to 6 miles : 600 V D.C. 20 to 30 miles: 3 000 V D.C. 7 to 15 miles: 11 000 V A.C.

QUESTION	*SOUTH AFRICAN RAILWAYS*	*CENTRAL INDIAN RAILWAYS*	*SOUTHERN INDIAN RAILWAYS*	*ASSOCIATION OF AMERICAN RAILROADS*
4. *What is total number of sub-stations?*	61	16	2	No particulars
5. *Are intermediate switching or paralleling stations placed between substations?*	Yes, on some sections and at junctions	Yes	Yes	D.C. systems - Yes A.C. systems - No
6. (a) *Are open wire telecommunication circuits altered, e.g. cabled after lines are electrified? If so, why?*	In some cases communication circuits are rebuilt to new standards having regard to distance from transmission lines, transposition, etc.	No	Yes, to mitigate interference with communication circuits	Usually cabled
(b) *If so, are costs charged against cost of electrification?*	No; not generally done, but depends on the nature of work		Yes	Yes
OVERHEAD LINE				
8. *What is material, size and arrangement of overhead contact system :*				
(a) *Main lines?*	Copper catenary and contact wire; simple catenary system. Cape Suburban : .375 sq. in. Natal: .15, .25 and .375 sq. in. Transvaal: .15 and .25 sq. in.	Bombay to Kalyan: .625 sq. in. comprising .375 sq. in. copper catenary and .25 sq. in. copper contact wire Beyond Kalyan : 1 sq. in. comprising .2 sq. in. auxiliary copper catenary, .3 sq .in. contact wire	.2 sq. in. cadmium copper contact wire, suspended from .25 sq. in. copper catenary	Either simple or compound catenary, 4/0 bronze contact wire widely used
(b) *Branch lines?*	As above	Some reduction is made	—	Not normally electrified
(c) *Sidings?*	As above, but some 7/.128 steel catenary in inland areas	Some reduction is made	Steel catenary with .15 sq. in. copper contact wire	—
9. *What types of construction are used for the supports:* (a) *Single track,* (b) *Two track,* (c) *Multiple track,* *State also for main lines, branch lines and sidings where the construction differs,*	(a) to (c) Varies from single track cantilever to single, double and lattice type steel structures spanning multiple tracks	(a) to (c) Varies from single track cantilever to special bridges spanning multiple tracks	(a) and (b) Girders with cantilever brackets (c)Gantries supported on girders, or lattice posts	(a) Wood or steel poles with bracket arms (b) and (c) Steel poles, either bridge or cross catenary support for main catenary
(d) *Have you provided mechanical and electrical independence of tracks? If so, how has it been obtained, particularly at junctions?*	(d) Yes. Section insulators are inserted at junctions	(d) There is no mechanical independence, except at stations and on the Ghat section where up and down structures have been separated where possible because of liability to rock falls	(d) Yes, overlap spans are provided at junctions	(d) Yes, high speed trolley breakers provide electrical independence when required

QUESTION	*SOUTH AFRICAN RAILWAYS*	*CENTRAL INDIAN RAILWAYS*	*SOUTHERN INDIAN RAILWAYS*	*ASSOCIATION OF AMERICAN RAILROADS*
What is the average distance apart of structures on tangent track?	210 to 220 ft.	220 ft.	220 ft.	250 to 300 ft.
What is the normal height and minimum height of wires above rail:				
(a) *in open track?*	16 ft. 6 ins.	(a), (b) and (c) Suburban: 16 ft. 6 ins. - 18 ft.	16 ft. 6 ins. to 17 ft. 3 ins.	Average about 22 ft.
(b) *at level crossings?*	15 ft. to 20 ft.	(a), (b) and (c) Main line: 18 ft. - 20 ft. 6 ins.	18 ft.	15 ft. 6 ins. (minimum) to 26 ft. (maximum)
(c) *in stations?*	Variable		As (a)	
(d) *in tunnels?*	13 ft. 10 ins.	14 ft. 10 ins. in tunnels and bridges	12 ft. 6 ins.	
3. (a) *What are the average and minimum permitted clearances between live metal and earthed metal or other structures?*	6 ins. minimum 10 ins. average	6 ins. minimum 10 ins. normal	6 ins. minimum 15 ins. normal	1 in. minimum Average not available
(b) *between minimum height of contact wire and clearance gauge of rolling stock?*	10 ins.	9 ins.	6 ins.	5 ins. to 15 ins. above load height
Are these clearances increased in special circumstances? e.g. in tunnels, through which steam locomotives pass, and by how much?	No	No	No	Yes, if possible. In some cases periodic cleaning of insulators is necessary because increased clearance cannot be provided
4. *What measures have been taken to ensure the safety of the enginemen of steam locomotives running on tracks provided with overhead contact wires, specially as regards the handling of long fire tools or the prohibition from climbing on to the higher parts of locomotives and tenders?*	Staff prohibited from climbing on higher parts of locomotives and from using fire irons under electrical equipment. Danger notices attached to all steam locomotives and tenders	Instructions have been issued to steam locomotive crews not to climb on top of engines and tenders	Staff are prohibited from getting on tenders and using fire irons on electrified sections. Special warning notices are exhibited	No information
5. (a) *Have these clearances in Questions C. 12, 13 and 14 been effective*	Yes	Yes	Yes	Yes
(b) *Would you propose to increase or reduce them for future work?*	No	It is proposed to increase the minimum from 16 ft. 6 ins. to 17 ft. 6 ins. in tunnels	No	No
(c) *Would State legislation be necessary to allow you to reduce them?*	No	Yes	No	No, in general

QUESTION	*SOUTH AFRICAN RAILWAYS*	*CENTRAL INDIAN RAILWAYS*	*SOUTHERN INDIAN RAILWAYS*	*ASSOCIATION OF AMERICAN RAILROADS*
16. *State any experience you have of prestressed concrete structures*	None	None	None	Not generally used
17. *To what extent is your choice of structure determined by availability of materials?*	Steel available and used	Steel has been and is available	—	Cost is the determining factor; all materials are available
19. *What provision do you make for avoiding damage from atmospheric disturbances, e.g. lightning stroke?*	Lightning arrestors and surge absorbers fitted to overhead track equipment at substation feeding points and mid-section, also on all locomotives and motor coaches	Lightning arrestors on overhead lines outside track cabins and horn gap discharge arrestors every mile on the overhead line	Lightning arrestors are provided at regular intervals	Varies widely according to liability to lightning
20. (a) *Cost per single track mile erected on level tangent double main line tracks, assuming no special site difficulties and that a substantial scheme is in hand :*				
(i) *including provision of foundations*	£ 5 960	46 909 rupees	Not available	Not available
(ii) *excluding provision of foundations*	£ 5 300	Not known		
(b) *Actual total cost of overhead equipment per single track mile, adjusted to January 1, 1953 prices, of an actual electrified section of line, including all its special work at junctions, sidings, stations, tunnels, etc. :*				
(i) *including provision of foundations*	£ 4 700	1,15'600 rupees per single track mile of 2-track construction on tangent track equipped with 0.75 sq. in. double copper, including cost of supply and installation of foundations, structures and overhead equipment and bonding of running rails		
(ii) *excluding provision of foundations*	£ 3 900	Not known		
21. *Do you do this work by your own labour or do you employ contractors for it?*	Railway administration	Contractors, except for minor works	Both	Have been handled both ways

QUESTION	*SOUTH AFRICAN RAILWAYS*	*CENTRAL INDIAN RAILWAYS*	*SOUTHERN INDIAN RAILWAYS*	*ASSOCIATION OF AMERICAN RAILROADS*
12. (a) *What were the corresponding costs for the actual scheme of altering structures, etc., to obtain the necessary clearances?*	On a section of 30 miles of line, the cost for repositioning signals, for removal of power and telegraph crossings, cutting of trees, etc., is £ 2 000	6,49,000 rupees, £ 48 670 for main line electrification (1930)	No information	—
(b) *Would these costs have been materially increased or decreased if a different system (involving larger or smaller clearances) had been adopted?*		(b) Slightly if A.C. is used	—	—
(c) *If so, by how much? (approximately)*		(c) 5 %		
13. *Have you had complaints of interference with either:* (a) *signals?* (b) *telecommunication circuits?* (c) *radio?* (d) *television?* *In each case, what complaints have been received, and how have they been overcome?* (e) *What restrictions are placed on you by State legislation in regard to these matters?*	(a) One or two isolated cases have occurred with signalling interference owing to faulty anode firing of rectifiers. A special anti-50 cycle relay is fitted to each rectifier (b) Occasionally, when wave filters have been faulty (c) No (d) No experience (e) Complaints are referred to Co-ordinating Committee	(a) No (b) No (c) No (d) No (e) Nil	No	This has not been a major problem since parallel communication circuits were usually placed in cable at the time of electrification
14. *State frequency of failures of overhead equipment, expressed as:* (a) *Number of failures per single track mile equipped per year*	(a) All-in average one failure per 100 S.T.M. per year	(a) 2.58 failures per 100 single track miles	(a) One sixth	—
(b) *Availability for use, giving definition of availability used*	(b) Approximately 99 %. (Average period line is available to traffic divided by total available time.)	(b) 99.98 %. (Plant or O/H equipment available for traffic purposes without an outage during the year.)	(b) 100 %, since there have been no breakdowns of long duration and maintenance work is carried out at night when there is no service	
15. *State the measures taken to guard against danger from a sagging or broken wire*	None, except for adequate safety factors used in design and well organised maintenance and inspection staff	None	The line is patrolled every day and inspection made nightly for defects	

QUESTION	*SOUTH AFRICAN RAILWAYS*	*CENTRAL INDIAN RAILWAYS*	*SOUTHERN INDIAN RAILWAYS*	*ASSOCIATION OF AMERICAN RAILROADS*
SUBSTATIONS				
26. *What type and size of equipment is installed in substations, and specify any features to which you attach importance*	2.0 mW rotaries on 1 500 V system; on 3 000 V system 1.5 to 3.0 mW rectifiers and in Natal 2.0 mW motor generators	2.5 mW rotary converters, 3.0 mW rectifiers at one substation	2 × 0.75 mW rectifiers in each substation	Varies widely from system to system
27. (a) *Is the converting equipment suitable for regenerative electric braking?*	Yes, in Natal	Yes, on main line	No	Yes
(b) *Is it used for this purpose?*	Yes	Yes		Yes, on Milwaukee, Virginian, Great Northern and others
28. (a) *Are filter circuits installed?*	Yes, at 3 000 V at mercury arc rectifier substations	Yes, in rectifier substations	Yes	Yes, on some D.C. electrifications
(b) *What benefit has been derived from them?*	Reduces interference in communication circuits	Inductive interference in neighbouring communication lines has been reduced	Interference is not experienced	Reduced harmonics in supply system
29. *Give actual total cost of substation equipment, adjusted to January 1, 1953 price levels for the actual section of electrified line used in question C. 24 above :*				
(a) *excluding cost of building work*	Not available	(a) —	Not available	Not available
(b) *including cost of building work*		(b) 130,23,778 rupees (for suburban and main lines, 1930)		
32. (a) *Are substations attended?*	In general, no except for some in Natal	4 attended, 12 unattended	No	Some are attended, some are remote controlled
(b) *Are substations and/or intermediate stations remotely-controlled, and by what method?*	In general, yes from nearest signal cabin. A few, in Capetown suburban area, are controlled from a Central Control Room	By supervisory control system	Yes, from a Central Control Room	

SECTION D.

QUESTION	*SOUTH AFRICAN RAILWAYS*	*CENTRAL INDIAN RAILWAYS*	*SOUTHERN INDIAN RAILWAYS*	*ASSOCIATION OF AMERICAN RAILWAYS*
MOTIVE POWER UNITS				
1-12. *See Tables III and IV*				
13. *What arrangements are made for heating passenger trains?*	Transvaal : Electric boiler on locomotive-hauled trains and electric heaters in multiple unit trains Natal : Coal-fired boiler, to be superseded by oil-fired boiler	—	—	Locomotive - hauled train : steam heated by boiler on locomotive Multiple unit trains: heated electrically
19. (a) *What is normal driving crew in passenger service?*	(a) and (b) Driver and Driver's Assistant in locomotives	(a) and (b) Driver and Assistant Driver	—	(a) and (b) Two enginemen
(b) *What is normal driving crew in freight service?*				
(c) *What is normal driving crew of motor cars?*	Driver	Motorman		One engineman
22. (a) *State annual mileage per motor car*	57 000	96 000	No particulars	No particulars
(b) *State annual mileage per locomotive*	75 000	72 000		

[656 .254]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

16th. SESSION (LONDON, 1954).

QUESTION 5.

Radiophonic communications in railway working.

REPORT

(America (North and South), Australia (Commonwealth of), Burma, Ceylon, Denmark, Egypt, Finland, India, Indonesia, Irak, Iran, Republic of Ireland, New Zealand, Norway, South Africa, Sweden and the United Kingdom of Great Britain and Northern Ireland and the territories for whose international relations the United Kingdom is responsible).

(Continuation and end) (*).

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Aerials (Antennas).

The transmitting aerial is required to perform two functions; firstly, to launch the wave into space, and secondly, to exercise a directional effect on the transmission. Regarding the latter function, an aerial may be required to be omni-directional, that is, to radiate equally in all directions which make the same angle with the vertical, or it may need to concentrate the radiation in a particular direction or directions. A single vertical wire is omni-directional, but non-directive elements can be combined to form a directive array, which may be large and complicated, although in general, the higher the frequency, the smaller and less complicated mechanically can be the array.

Directive aerials can be made up of active elements connected to the transmitter, and passive elements which are excited by the field associated with the former. The resulting currents in the passive elements set up fields which combine with those of the active elements, thus affecting the directional characteristics of the system. The design problem is to locate the elements so that their individual fields will be additive in the desired transmission direction and in opposition in all other directions, and at the same time to make the electrical efficiency of the system as high as possible.

The use of passive elements can be illustrated in the case of a single vertical wire, which on its own would be omni-directional. If a wire is placed parallel to it at, for example, a distance of rather less than quarter of a wavelength away, the system will give maximum transmission in one

(*) The first part of this report appeared in the *Congress Bulletin* for September 1953, see page 615.

direction along the line joining the two elements, and minimum in the opposite direction. Which of these two directions is maximum and which is minimum depends on the relative dimensions of the system. When the passive element is on the same side of the active element as the direction for maximum transmission it is known as a « director » and, if on the opposite side it is termed a « reflector ».

An aerial can, of course, be used for transmission or reception, and the same features regarding directivity apply in both cases.

Point to point communication is an obvious application for directional antennas for both transmission and reception. When it is permissible for a receiving aerial to be directive, for example, when reception is required from one direction only, the benefits are two-fold. Firstly, the aerial efficiency is increased for reception from the desired direction; and secondly, reception from interfering sources is reduced, provided those sources do not lie too close to the transmission path of the wanted signal. In the case of interference from a particular source, careful consideration to aerial design may be especially necessary.

As previously mentioned, the shorter the wavelength the more readily can aerials be made directive, and with microwaves it is practicable to use concave metal mirrors, and to transmit a relatively narrow beam, the width of which is defined as the angle between the two directions on each side of maximum transmission where the radiation is half power relative to the direction for maximum power.

For railway purposes, one of the most important requirements is compactness, particularly in the case of mobile stations, and even with fixed stations, large complicated arrays would usually not be practicable. Fortunately, the frequencies allocated for railway use are, in most cases, sufficiently high to enable reasonably compact arrays to be provided even when directive aerials are required. Except in the case of fixed point-to-point communication, highly directive aerials are not usually needed. Simple directive aerials might be applicable in the case of a fixed station communicating with mobile units on a length of line, the aerials being either omni-directional or bi-directional depending on circumstances.

In the case of a marshalling yard, it is probable that an omni-directional aerial will be required, but this is not so in the British Railways yard at Whitemoor, where, owing to difficulties in finding space on the locomotives, a horizontal half-wave dipole was fitted on top of the cab, and a horizontal dipole was used for the fixed station. By a half-wave dipole is meant an aerial which has an electrical length of one half wavelength and is, in effect, fed at its mid point. When erected vertically without reflectors or directors, it is omni-directional, but used horizontally, it is bi-directional. The directive characteristics of these aerials was not a disadvantage in this case because the yard is relatively long and narrow.

Possibly one of the most difficult problems associated with aerials for railway use arises in connection with the fitting of aerials on locomotives, and development in compact designs will naturally be of interest to railway authorities. The most popular type of aerial used on engines and on other mobile units appears to be the quarter wave unipole, a unipole being a single conductor fed from one end, often in the form of a vertical rod. In some cases use is made of a ground plane or artificial earth plane made up of, for example, a number of horizontal metal rods radiating out from a point just below the lower end of the aerial. This results in a system which is equivalent to a half-wave dipole, the lower half being the image of the unipole reflected in the ground plane. In order to match the feed cable to the aerial, sometimes a folded quarter wave unipole with ground plane is used. This consists of two closely spaced parallel conductors, connected together at the top, each having an electrical length equal to one

quarter wavelength, the lower ends being connected, one to the feeder cable and the other to the ground plane. One design, a compressed quarter wave end fed vertical aerial with top capacitance loading, probably is worthy of mention. This aerial is mounted on the locomotive boiler which acts as a ground plane, and for a frequency of about 170 Mc/s. the construction consists of a 2 1/2 inch diameter metal tube, with a disc top, having an overall height of about 11 1/2 inches (fig. 18).

Fig. 18. — Compressed quarter wave aerial for use on locomotives.

It might be profitable for those railway administrations which find difficulty in locating aerials on locomotives, to investigate the use of higher frequencies and smaller aerials. At present it is the normal practice in the case of radio communication with trains to employ frequencies in the VHF band, usually of the order of 80 or 160 Mc/s. Experiments to investigate the practicability of the UHF band would seem justified, particularly as such frequencies would assist in the case of communication in tunnels.

It may be said that, in general, the aerials employed by the various railway authorities for VHF communication with mobile units, both for the mobile units themselves and for the associated base stations, are of the types one would normally expect for these frequencies. Regarding the base stations, aerials mostly take the form of either half-wave dipoles, mainly vertical, or quarter-wave unipoles with ground plane. The former are sometimes multi-element and include « delta matched » aerials, in which the open wire feed pair is fanned out and connected to points symmetrically located at a specific distance on each side of the mid point of the aerial in order to match the feeder to the aerial. In some cases the quarter-wave unipoles are of the folded type.

With some « walkie-talkie » portable sets, the aerial may be a handicap in railway working owing to its getting in the way of the operator, when, for example, he needs to go between vehicles. Aerials for these sets are usually quarter-wave unipoles constructed of flexible rod or « springy » ribbon. The size of the aerial being proportional to wavelength, increase in the frequency will result in a smaller aerial and thus any such disadvantage is more apparent on frequencies of about 80 Mc/s than those around 160 Mc/s. One type of set operating at about 160 Mc/s incorporates the aerial in the carrying strap, and this is a great advantage as it facilitates the movements of the operator.

Recently a portable transmitter has been produced in the U. S. A. designed to operate in the 152-174 Mc/s frequency band. The complete transmitter, including self-contained dry batteries and microphone, weighs only 1 lb. 13 ozs. It has a power output of 20 to 40 milliwatts and a tested range up to 5 miles. A rigid chrome-plated loop antenna doubles as the carrying handle (fig. 19). To transmit it is only necessary to press a button on the side of the unit.

Turning to fixed point to point services, the aerials employed appear to be of normal conventional types, two of which have not been mentioned above, namely the Windom and the Rhombic, used by some railway organisations in the higher medium frequency and lower high frequency bands.

Regarding the former, if a T-aerial is defined as a horizontal wire with a single down lead connected at its mid-point, the

Windom type aerial can be looked upon as an unsymmetrical T-aerial having a half-wave top. The single down lead connection is displaced from the mid point by a distance depending on frequency and the lead is run at right angles to the aerial for a distance of not less than one third of the aerial's length. The arrangement is employed in order to match the impedance of the lead to that of the aerial.

Fig. 19. — Handie transmitter can also be obtained with a single loop antenna so that a man can hook it over his arm for carrying.

The Rhombic aerial is made up of four wires, each of which should preferably be at least two wavelengths long, arranged in the form of a diamond in the horizontal plane. A terminating resistance is connected at one end of the diamond and the feed pair at the opposite end. The aerial has very effective uni-directional characteristics, but it occupies a large area. By omitting the terminating resistance which absorbs half the power, the aerial can be made bi-directional.

In general, it can be said that the aerials used by the railway administrations are all reasonably satisfactory, and it is difficult to draw comparisons between them. There does not seem to be any great probability of revolutionary new designs, but some improvement in aerials for mobile units to enable a lessening of the problems involved in finding mounting space is desirable.

TRANSMITTING AND RECEIVING APPARATUS.

Probably the most essential requirement of radio equipment for railway use is that it shall be entirely reliable. At the same time it should be robust and compact, particularly where mobile units are concerned. On locomotives it is especially important that the apparatus should be shock-proof and dust-proof (fig. 20).

It is usually essential that faulty equipment should be repaired with the utmost speed and probably this can best be effected by means of plug-in units which can be changed for spares, enabling the faulty apparatus to be repaired at a maintenance depot. With this system of maintenance the local staff do not require to be highly specialised in radio work, although it is preferable that they should be capable of locating minor troubles such as faulty valves. In some cases means of testing valves may be incorporated in the equipment, but this may adversely affect the compactness of the apparatus. It is, therefore, a debatable point as to how much of the fault location should be carried out on site, but this is a matter which each organisation must decide for itself depending upon the type of maintenance staff available, and on the possibility of incorporating in the equipment facilities enabling quick checks to be made.

It will be appreciated that in order to ensure the highest possible reliability, periodical maintenance and overhaul of equipment is essential, although it is noted that on some railways this has not yet become a regular feature. The general practice appears to be that maintenance is carried out by railway staff, but in one case it is intended to have this work done by a contractor's staff : it may be that this

is only to be a temporary measure until suitable railway staff can be trained or recruited.

There can be little doubt that maintenance of railway radio equipment should be the responsibility of railway staff, but the introduction of extensive radio communication schemes would, no doubt, in the case of many railways, necessitate the recruitment of additional staff and adoption of some form of training scheme.

Power output.

The output power of the transmitters used by various railway administrations varies over a considerable range. For fixed point-to-point services on frequencies between 1.5 and 15 Mc/s powers up to about 1 500 watts are employed.

In the case of base VHF stations for mobile services, power usually ranges from about 20 to 100 watts, while mobile units employ a power of between 5 and 25 watts,

Fig. 20. — Specimen of heavy duty railway radio equipment.

Returning to the requirements of compactness and reliability of equipment, it is unfortunate that these two needs tend to be incompatible. However, it is possible that recent developments in « printed and potted circuits » and possibly in the use of germanium crystals, will aid in overcoming the difficulty in producing a compact set without sacrificing reliability.

or rather more in a few cases. The walkie-talkie type of set normally has an output power of between 0.1 and 1 watt.

With stations operating on VHF or higher frequencies, a large increase of power will result in only a small increase of range when reception is beyond the line of sight distance, and it is for this reason that transmission to points beyond the

optical horizon necessitates the provision of repeater or relay stations which amplify the received signal and then retransmit it. Where it is necessary to cover large distances, chains of such repeater stations are provided.

Systems of communication and calling methods.

Both duplex and simplex systems of working find application with railway radio. For fixed point-to-point services which are provided to give normal trunk telephone facilities, duplex functioning is necessary. With mobile services, either duplex or simplex can be employed, choice being dependent on the communication requirements and sometimes on the stipulations of the licensing authorities. When communication is only required between each mobile unit and the base station, and it is desired to prevent contact being made between mobile units, duplex working would satisfy the conditions; but if communication is specified between mobile units as well as with the base station, simplex working is preferable for practical reasons.

Calling of mobile stations is, on most railways, effected by means of call signs which are frequently received on loudspeakers, but some railways have adopted automatic selective calling employing telephone dials, although it is doubtful whether the additional complications and cost of selective systems are really justified.

Power supplies.

Reliable radio communication is obviously dependent upon an efficient power supply. In the case of fixed stations where the local A.C. mains supply, either railway or commercially owned, is available, it is usual to make use of this source of power provided that reliance can be placed upon its stability. It may be considered necessary in some instances to instal a stand-by petrol or oil driven set to cater for times of failure of the normal mains supply. A decision as to whether such a stand-by is necessary must be based on consideration of the circumstances relating to the individual stations concerned.

With mobile equipment and, in particular, with walkie-talkie sets, the provision of a power source is somewhat of a problem, since it is usually necessary to limit the size and weight of equipment to a minimum.

Radio equipment installed on steam locomotives can often be supplied from steam turbo generators, while accumulators are usually employed for equipment installed in brake-vans (cabooses). In some cases, the accumulators are charged at the depot, but often charging is carried out en route.

Both accumulators and dry batteries find employment in walkie-talkie apparatus, and one of the difficulties in connection with portable equipment is associated with the provision of efficient and compact lightweight batteries and accumulators. It is thought that recent advances in the development of accumulators and dry batteries for portable equipment will eventually aid materially in solving this problem, although at the present time the improved types of cell are rather costly. Developments in the use of transistors will no doubt assist by reducing battery requirements.

PROPAGATION PROBLEMS.

Of great importance in radio communication are the various factors which tend to lessen the intelligibility of the received signal, and which may be summarised briefly as follows :

(1) Fading and distortion due to the waves from the transmitter taking two or more different paths to the receiver, where interference takes place between the waves. Such interference can occur :

(*a*) between a ground wave and a wave reflected by the ionised layers, which are subject to influence during sun-spot activity and to seasonal changes resulting in variable conditions;

(*b*) between two waves differently reflected from the ionised layers; or

(*c*) between a directly received wave and one reflected from houses or structures in the vicinity.

(2) Noise and distortion due to interference from other radio stations as a result of overlap of the frequency bands employed by the wanted and interfering stations.

(3) Noise resulting from :

(*a*) « atmospherics » due to lightning discharges, possibly thousands of miles away, such disturbances usually being negligible on waves below 15 metres;

(*b*) « man-made interference » from electrical machines including electric traction circuits.

(4) High attenuation and blotting out of signals by rain and heavy mist on frequencies over about 10 000 Mc/s or even lower in some exceptional instances.

With regard to difficulties in built-up areas compared with open country, one would expect any such difficulties to vary with frequency, and what trouble has been experienced seems to be confined to frequencies in the VHF band. Experience with higher frequency bands is, of course, limited. Information from the Association of American Railroads is to the effect that they have not experienced any particular difficulty in built-up areas as opposed to open country. The statement is made regarding the Norwegian State Railways that experience on one route passing through a very built-up area has not demonstrated any particular trouble. However, experiments carried out in Norway show that, operating on 80 and 160 Mc/s with a transmitting power of 15 watts, it is difficult to maintain good communication over distances exceeding 10 kilometres in built up areas, whereas with stations on mountain tops a range of 160 kilometres can be attained.

It is reported from Denmark that shadows and interference due to reflections from buildings have been experienced, but no serious difficulties appear to have been encountered on railroads in the U. S. A. On the lines of the London Transport Executive, reflections from structures have been found to reduce signal strength in certain places, but when such loss of signal occurs it is the practice to move the mobile units until the signal strength has been increased sufficiently. As in the case of data regarding built-up areas, the reports on reflection problems appear to refer only to the VHF band.

Communication with mobile units is adversely affected by tunnels and cuttings, and in this connection, it is understood that continuity of radio signals in tunnels is not generally catered for in the U. S. A., but that with inductive systems, a single wire strung through the tunnel ensures continuity of communication. Tests carried out on British Railways indicate that frequencies of 450 Mc/s and above can be effectively transmitted through both straight and curved tunnels, but the limiting frequency, between 160 and 450 Mc/s, was not determined.

Serious interference due to solar disturbance and sun-spot activity seems to be confined to tropical countries, where such phenomena naturally will be most severe. In these countries humidity is often a cause of failure and is sometimes countered by placing a high wattage lamp in the apparatus.

Interference from electrical apparatus does not, in general, appear to be common, but it is reported from Denmark that occasional disturbances are experienced from diathermy apparatus. The Association of American Railroads explains that the combination of VHF and frequency modulation has eliminated electric traction and similar interference. It can be noted that both frequency and amplitude modulation is employed in existing railway equipment and it is probable that, in the VHF band, the former is the more popular. On the basis of the opinions received, it may be implied that considerable interference from

electric traction is possible on frequencies around 80 Mc/s and below, but increasing the frequency to 160 Mc/s reduces the interference to negligible magnitude. This inference is, however, open to confirmation.

The A. A. R. suggests that with modern equipment, interference as a result of overlapping has been avoided, but there have been a few cases where interference has been caused by inter-demodulation occurring in the input stages of receivers, which are presumably of an older type. The Indonesian State Railways report that breaks in continuity of reception do occur on account of interference from other transmitters.

If we stretch the definition of interference, we can include mechanical noise on locomotives under that heading. In America many of the locomotives fitted with radio are diesels, on which noise has not been a serious problem; but trouble has been experienced in that country with steam locomotives in the past, and one method of overcoming it is by the use of close-speaking, noise-cancelling microphones. In Norway special precautions are taken to overcome noise on the locomotive by reducing the modulation level and placing cotton in front of the microphone capsule behind rubber protection.

It has been found in Sweden that in electric shunting locomotives, noise can be sufficiently overcome by the use of loudspeakers for calling purposes and handsets for speech.

OPERATING RULES.

In general, operating rules should embody such of the regulations laid down by the licensing authority as are appropriate to the guidance of the staff, and whilst in most instances details of these regulations are not available to us, it would appear that they are mainly intended to ensure that the radio stations are operated in such a manner as not to interfere with the operation of other stations in the same or other radio services.

Rules in regard to the detailed manipulation of transmitters and receivers must of necessity vary according to the type of equipment employed, local circumstances and the specific nature of the communication required. There are, however, certain stipulations which have general application, and as the greatest developments have taken place in the U. S. A., the Railroad Radio General and Operating Rules issued by the Association of American Railroads as required by an order of the Federal Communications Commission are attached as Appendix B.

The Association of American Railroads in October, 1952, adopted a specification entitled « Operating Techniques for Operational Train Radiotelephone Communications Systems ». The purpose of this specification was to provide information to serve as a guide to railroads using radiophonic or inductive carrier communication, in the preparation of special or supplemental instructions to their employees to aid them in the use of such systems. A copy of this specification forms Appendix C to this report.

Appendices B and C are quoted in full as they may prove useful to other Administrations in formulating their rules.

RECENT DEVELOPMENTS IN TECHNIQUE.

Microwave radio.

During the war, rapid advancement was made in the development of VHF apparatus and in microwave technique, so that not only are there many more frequency allocations available, but also systems are produced which split each of these frequency allocations into a number of independent channels all transmitted on one radio beam, and it may be added that the character of these waves, in particular microwaves, is such that they can be beamed by the use of relatively small reflectors, thus minimising interference. In general, it may be said that the higher the frequency i.e. the shorter the wavelength, the easier it

is to confine the waves within a narrow beam. As examples of typical practice, the 6 cm system, mentioned in the next section under « Pulse modulation », uses a beam width of about 4°, while the 60 cm system has a beam width of about 30°.

It should be noted that the waves are not confined entirely to the beam. The radiation intensity varies with the angle of radiation from the aerial, and the beam width is defined as the angle between the two directions corresponding to half maximum power, and some radiation exists outside the beam so defined.

The « line of sight » character of these waves necessitates, except for short distance circuits, the use of repeater stations comprising receivers and transmitters with reflectors on the top of high towers. The separation of these stations, which can be unattended, depends on the character of the terrain and the height of the reflectors, but an average separation of 30 miles might be assumed.

Such systems are so expensive that the cost can be justified only by a considerable volume of message traffic or most exceptional difficulties in the maintenance of pole routes as in territories where sleet storms are prevalent.

An example of the former, although not on a railway, is the project of Western Union Telegraph Company of America to replace major trunk wire lines with super high frequency radio relay systems, and this has been largely carried out.

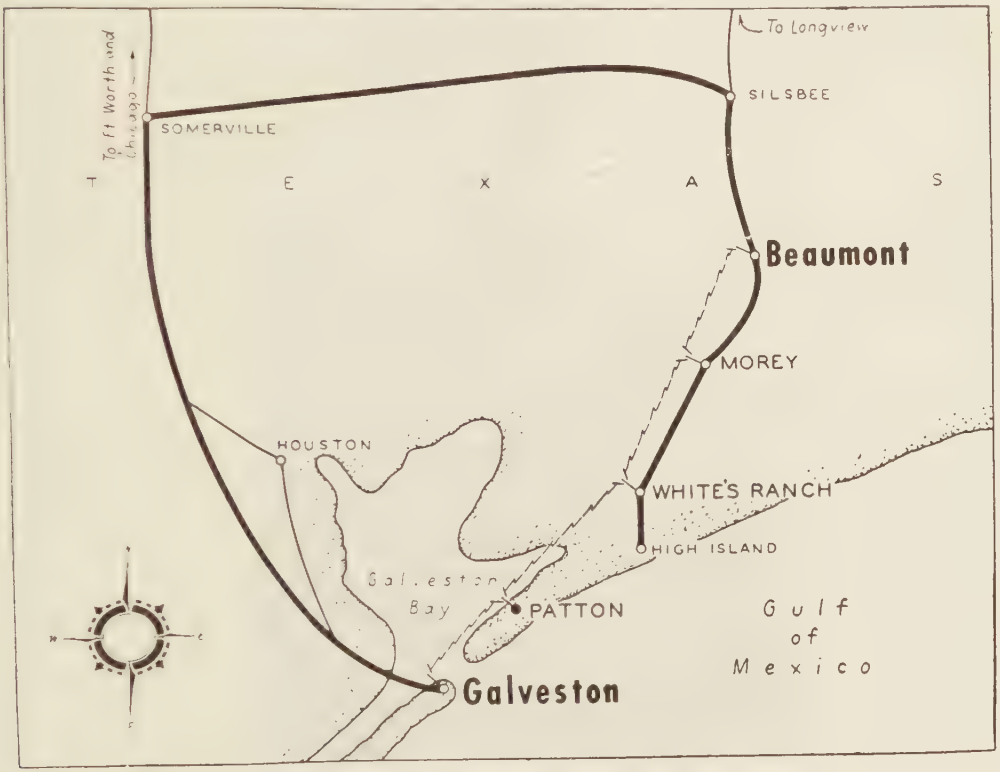


Fig. 21.

Frequencies in the microwave region have been made available to the railroads in the U. S. A., for direct point-to-point communication, and two railroads have adopted such systems, covering a distance of approximately 175 miles and operating on frequencies in the vicinity of 6 700 Mc/s.

Fig. 22. Mounting of parabolic antennas at Patton.

Whilst little information in regard to these installations is available to us, it is possible that microwave radio has been adopted because of the difficulty and cost of maintaining line wires in particular areas.

Pole line routes require constant maintenance and replacements. Human nature being the same the world over, thousands of insulators are broken every year purely for the devilry of it. Poles and cross-arms decay and must be replaced. Copper wire will corrode and break. In territories where sleet storms occur, heavy ice loads break wires and poles for miles.

The fewer the number of wires, the greater the maintenance costs per wire mile because the proportion for poles increases. By the use of phantom, carrier and other means of employing wires for two or more messages simultaneously, the maintenance charges per circuit are reduced; but if a disastrous sleet storm destroys extended sections of pole route, restoration costs are high, and what is perhaps more important, communications are disrupted for pro-

longed periods. These expenses and troubles are avoided by using multi-channel microwave radio which requires only the terminal equipment and repeater stations.

One instance has come to notice where the system has been used to cross a bay. The Atchison, Topeka and Santa Fe Railroad (U. S. A.) has placed in service a microwave radio relay system between Galveston (Tex.) and Beaumont, an air line distance of 68 miles, across Galveston Bay (fig. 21). Previously, the railroad telegraph and telephone communication between these cities was handled by line wires on railroad pole line via Somerville and Silsbee, a total of 315 miles. The new microwave system carries eight duplex voice channels and six FM telegraph carrier channels, by means of which 22 people can communicate simultaneously by telephone and telegraph.

At Galveston, microwaves are directed from a parabolic antenna on top of a 116 ft. office building, towards the first repeater station at Patton (fig. 22). Here the radio waves are received, amplified and directed toward the next repeater station at White's Ranch. The process of receiving, amplifying and redirecting takes place at each of the three repeater stations until the microwaves reach the terminal at Beaumont. The process operates in the same manner for transmission back from Beaumont to Galveston.

The availability of beamed radio opens up a new field, but a most important point to be borne in mind in considering its introduction is that, if line wires have to be retained for intermediate and local circuits, then the high cost of installing microwave systems will be the more difficult to justify.

Pulse modulation.

One of the important developments of the last ten years or so is pulse modulation technique, in which the carrier wave is transmitted in very short pulses which can be used to convey the speech in one of several ways; for example, by varying the amplitude, the duration or timing of the pulses in accordance with the speech to be transmitted. This technique, which in essence is a sampling process, is applicable to both single and multi-channel systems. Usually 8 000 or 9 000 pulses are transmitted per second for each speech channel, the speech being sampled this number of times per second, and data regarding each sample is conveyed by one of the pulses.

In time-allocation multiplex systems the pulse trains corresponding to the various channels are interlaced. The first pulse can be taken to represent the first sample of the first channel, the second pulse the first sample of the second channel, and so on. When the first sample of each channel has been transmitted, the second samples are then transmitted in the same order and the sampling continues on this basis at the rate of 8 000 or 9 000 per second, any necessary synchronising pulses being introduced at the appropriate times.

In July, 1942, a time division multiplex system providing 8 duplex telephone channels and employing 8 000 pulses per second per channel was demonstrated in Great Britain by the Signals Research and Development Establishment of the Ministry of Supply, and in September of that year trial circuits were installed over a distance of 17 miles. In January 1944, the first production models operating on a wavelength of about 6 cms., were available and they were in operational use just before the invasion of Europe by the Allied Forces. Later, in 1945, American versions of the system appeared in Europe.

Another early system developed in Britain was designed to operate on a wavelength of about 60 cms., using 9 000 pulses per second for each channel, and providing twelve duplex telephone channels. With a transmitter power of 200 watts peak, the equipment would permit working over line of sight paths up to 100 miles in length.

In 1945, the Federal Telecommunication Laboratories of the International Telephone and Telegraph Corporation in the United States, demonstrated a 24-channel system.

The wide bandwidths required by these systems entail the use of microwaves, or at any rate decimetric waves.

The pulse system has advantages to offer in that high signal to noise ratios can be achieved, and multi-channel systems can be produced utilising relatively simple equipment which will enable channels to be terminated at intermediate repeater stations with less complication than is necessary with other systems. Thus, where reliable point to point multi-channel services of a fixed or transportable kind are required, the use of pulse modulated systems should not be overlooked by Railway Authorities, and it should not be forgotten that the radio frequencies employed for pulse modulation make possible the application of efficient beam transmission. The multi-channel pulse modulation system may also have some advantages over other forms of modulation with respect to maintenance.

EXTENT OF ADOPTION OF RADIO-TELEPHONY.

As distinct from wireless telegraphy which, as previously described, is extensively employed in some countries where land line communication does not exist or is difficult to maintain, it will have been gathered that very limited use is made of radio-telephony for train and yard-terminal purposes in the countries which have replied to the questionnaire, except in the U. S. A.

Extensive installations of radio and inductive carrier communication on U. S. railroads were begun about 1945. Such installations have increased steadily and the numbers of installations authorised and the types of service to which they are applicable at a date in 1952 are shown in the table hereafter.

The A. A. R. explain that since authorisations issued by the licensing authority are permissive rather than mandatory, a railroad may not have in operation all stations in the table. This is more likely to be true in the case of authorisations for mobile stations, since the licensing authority has encouraged railroads to obtain authorisations for the number of mobile units which they expect to use within a period such as a year beyond the actual date of the authorisation. Each base station, however, requires an individual authorisation and it may be assumed that nearly all the base stations are in actual use.

Type of Station	*Radio*	*Inductive*	*Total*
Train Service :			
Base	307	205	512
Mobile	5 393	1 306	6 699
Yard-Terminal Service :			
Base	259	18	277
Mobile	3 097	40	3 137
Total	9 056	1 569	10 625

It is appropriate to mention here that the U. S. A. is the only country which reports the use of radio inductive carrier systems, and that at the present time such systems operated by railroads and other bodies in the U. S. A. are not required to be licensed provided radiation from them does not exceed 15 microvolts per metre at a distance of approximately 1/6 wavelength from the transmitter.

The route mileage served by radio systems in the U. S. A. as at January, 1st 1952, was :—

Type of System	*Miles of Railroad*
Radio	28 804
Inductive.	4 299
Combination of radio and inductive	1 103
Combination of inductive and wire inter-communication . .	87
Commercial radio service used in railroad operation	299
Public radio telephone service on trains.	1 778

Since the introduction of radio has coincided with changes in operating conditions, improvements in facilities and replacement of steam locomotives by diesels, no reliable figures on economies arising from the use of radio communication systems have been compiled. All indications are, however, that radio systems on and with moving trains and in yard or terminal areas, have been adopted as a permanent feature in the U. S. A., from which it can be deduced that the administrations concerned are satisfied that the benefits accruing justify the cost.

In some of the countries for which we are reporting where radio-telephony has passed the experimental stage, it has been decided to extend the practices, especially in large marshalling yards and in connection with engineering work.

RADIO AS THE SOLE OR SUPPLEMENTARY MEANS OF COMMUNICATION.

In only one instance has it been stated that radio has replaced manual and visual signals, namely at the hump in a Swedish marshalling yard, to which reference has already been made.

Elsewhere, the use of radiophonic communication in railway operation is supplementary to, and has not superseded, existing methods of communication and signalling. This is important as it could be implied that, although substantial advantages are claimed for the use of radio, it has not been deemed sufficiently reliable and fool-proof to take the place of modern signalling and safety precautions.

Evidence is forthcoming that properly maintained radiophonic communication equipment is capable of a high degree of reliability in service, several railroads in the U. S. A. having compiled statistics indicating an availability of approximately 99 per cent. It seems inevitable, however, that some failures will occur at times, either through breakdown of apparatus or the existence of conditions preventing the satisfactory transmission or receipt of signals by radio.

It is an axiom of railway signalling that should a failure of apparatus occur it should be on the side of safety, and whilst it is inadvisable to be dogmatic and to ignore the possibilities of future developments, it is difficult to envisage reliance being placed solely on radiophonic communication for regulating the movements of trains on running lines, having regard to the hazards involved in failure to receive a message or to instructions so conveyed being misunderstood.

It may be that there is greater opportunity for radio to take the place of some of the existing means of communication in marshalling yards where many of the movements are made on instructions given verbally.

In this connection it is germane to refer to remarks made by a delegate from the Atchison, Topeka and Santa Fe Railroad at the 1951 session of the Communications Section of the A. A. R. He stated his administration had recently installed a new hump yard at Pueblo (Colorado) and that in some respects it was rather unique.

Though not large in comparison with some yards, it has, amongst other groups, 16 classification sidings, and in the aggregate for the yard as a whole some 30 miles of track. It is equipped fully with loud speakers, telephones and radio for general yard and terminal operation.

For controlling the speed of cars over the hump, it was decided that this could be entirely handled by radio. It is not without significance, however, that one signal was installed at the crest of the hump so that, in the event of complete failure of the radio, the signal could be used to enable humping operations to be carried on until repairs were effected. Although it was claimed that little time was lost due to failure of radio equipment, it might be a matter of some consequence at a much larger yard with more sidings, dealing with a greater volume of traffic, if reliance in the case of failure of radio apparatus had

to be placed on one fixed signal at the hump, and even more so, if no alternative means whatever of hump signalling were provided.

The supplementary nature of radiophonic communication is, in many instances, the criterion for its justification because of its virtue as a means of obtaining more economical user of locomotives and men. In other words, the adoption of radio results in the elimination of periods of unproductive time which may otherwise be incurred whilst waiting for telephone or other contact to be established. It is particularly of assistance in certain adverse atmospheric conditions, e.g., fog, falling snow, etc.

Whether radio will enable other existing apparatus for transmitting communications and signals in marshalling yards to be dispensed with remains to be seen, as it is only in recent years that radio has been employed extensively, and this mainly in the U. S. A. where the internal distances to be covered within the yards are often comparatively great.

Radio is an additional instrument of operation, and it is natural that a degree of reserve should be exercised before attempting to rely upon it as the sole means of communication, and particularly to withdraw existing facilities.

SUMMARY OF CONCLUSIONS.

(1) Before the second world war, there was little opportunity for railways to utilise radio-telephony, because the number of radio channels available was limited and technical development had not reached a sufficiently advanced stage.

(2) During the war, rapid advances were made in knowledge of the behaviour of the short waves with their relatively greater « channel availability », and in the development of transmitting and receiving devices.

(3) Licenses to operate radio stations have to be obtained from the appropriate body responsible for control of the government telecommunications services, and formerly the use of channels for other than military or other national purposes was greatly restricted. Since the war, more channels have become available.

(4) Except in countries where long-distance wireless telegraphy is permitted, there is little hope of railways being allocated the use of channels in the lower frequency bands, and the use of radio by railways lies in the employment of VHF and higher frequencies, the « line of sight » character of which minimises interference and enables the same frequencies to be employed simultaneously in different localities.

(5) The majority of frequencies allocated to railways in the countries covered by this report fall into two categories :—

(*a*) the VHF band — 70/80 Mc/s and 150/180 Mc/s;

(*b*) the higher end of the MF band and lower end of the HF band — 1.5 to about 15 Mc/s.

(6) The most extensive application of radio-telephony for railway purposes has been made in the United States of America, but administrations in some other countries have such installations or have carried out experiments.

(7) The uses to which radio-telephony has been, or is being, put fall into the following general categories :—

(*a*) Between front and rear ends of trains, i.e. driver and guard.

(*b*) Between trains or locomotives on the running lines.

(*c*) Between fixed points and trains or locomotives on running lines.

(*d*) Between trains and train staff on the ground.

(*e*) At marshalling yards and in terminal areas between supervisors and locomotive crews or employees on the ground.

(*f*) Construction of new railways.

(*g*) In connection with permanent way maintenance work.

(*h*) Signal & telecommunications engineering construction or repair work.

(*i*) Clearance of lines following blockage by accidents, storms etc.

(*j*) Control of railway-owned road collection and delivery vehicles.

(*k*) For security purposes, e.g. by railway police.

(*l*) For use by passengers on trains to connect with the public telephone network.

(*m*) Supplementary to wireless telegraphy where licensed, between fixed points over long distances.

(8) The use of radio-telephony as a means of instant two-way communication between the crew on a locomotive and the guard, conductor or brakesman at the rear end of a train has proved of value where a train is of considerable length as in the U. S. A., for example, where a freight train may be 1 1/4 miles or more in length.

(9) On U. S. railroads, where train movements are under the jurisdiction of train dispatchers, radio-telephony between officials at fixed locations and crews of trains or locomotives on running lines is used to increase the efficiency and enhance the safety of operation.

(10) Radio-telephony can be used in marshalling yards with advantage, where justified, to permit of prompt communication between a Yardmaster or Supervisor on the one hand and yard engine crews, or shunting staff on the other.

(11) The use of radio facilitates the transmission of instructions at marshalling yards when, under conditions of poor visibility, signals cannot readily be seen.

(12) Considerable use is made of radio-telephony in the U. S. A. for the more effective control from a central supervisory point of the movements of locomotives serving terminal depots, dock areas, factories and other siding-connected undertakings.

(13) The development of light-weight, compact and small portable radio transmitters and receivers capable of being carried by ambulatory staff has enabled quick communication to be established between a train and members of the train crew when on the ground; and in marshalling yards for directing movements, recording vehicle numbers, dealing with defective wagons and bad loads.

(14) Radio-telephony is used to advantage on civil and signal engineering work for the closer co-ordination and utilisation of men, material and equipment.

(15) The demand for a public radio-telephone service on trains is limited. Where provided, it is supplied as a convenience to the public at a financial loss to the railway.

(16) Radio equipment for railway use should be reliable, robust and compact. Considerable progress has been made by manufacturers in the production of equipment to meet these requirements.

(17) The most important requirement in relation to aerials for railway use is that they shall be compact. The higher the frequency the smaller and less complicated can be the array. In most cases, the frequencies allocated for railway use are sufficiently high to enable reasonably compact arrays to be utilised.

(18) Limitations imposed by the loading gauge on the size of aerials on mobile units, whilst reducing the range and coverage of the apparatus employed, have not had a serious effect.

(19) Power supplies for fixed stations can use local A. C. mains supply where available. Radio equipment on steam locomotives can often be supplied from steam turbo generators, whilst accumulators are usually employed for equipment installed in brakevans (cabooses), the accumulators frequently being charged en route by means of vehicle dynamos.

(20) There are a few installations where, by the use of a tone signal, a mobile station may cause the receiver of the nearest unattended base station to be connected to a remote line so that the mobile station may communicate via radio and remote line to a train dispatcher, who may be 100 miles or more distant.

(21) The U. S. A. is the only country which reports the use of radio inductive carrier systems and at present in that country such systems are not required to be licensed provided radiation from them does not exceed 15 microvolts per metre at a distance of approximately one-sixth of the wavelength from the transmitter.

(22) Beamed radio opens up a new field for fixed point-to-point communication. Developments in microwave technique have enabled systems to be produced which permit the frequency allocations to be split into a number of independent channels all transmitted on one radio beam.

(23) Microwave systems are expensive, but might be justified where there is a considerable volume of message traffic; where exceptional difficulty is experienced in maintaining physical circuits; or as a link to cross water to avoid a circuitous route. If line wires have to be retained for intermediate and local circuits, the cost of installing microwave systems is more difficult to justify.

(24) Where reliable point-to-point multichannel services of a fixed or transportable character are required, the use of pulse modulated systems should be examined.

(25) The use of radio-telephony in connection with train and yard working is supplementary to, and has not superseded, existing methods of communication and signalling, with the exception of one marshalling yard in Sweden.

(26) As many intangibles are involved, no reliable figures on economies arising from the use of radio communications systems have been compiled. All indications are that radio systems on and with moving trains and in yard or terminal areas have been adopted as a permanent feature in the U. S. A., which postulates that the administrations concerned are satisfied that the benefits accruing justify the cost.

(27) Where permitted by the licensing authority, use is made by railways in some parts of the world of wireless telegraphy between fixed stations over long distances. Such installations are usually in countries where land line communication is inadequate, is costly to provide or difficult to maintain. Radio-telephony is utilised as a secondary means of communication in some instances.

(28) Where in sparsely populated countries it is desired to establish communication between distant points and no physical route exists, it is advisable to examine the relative costs of radio vis-à-vis the erection of a pole route, subject to its being ascertained in the initial stages whether or not the licensing authority would permit the adoption of wireless communication between fixed points for railway purposes.

(29) There is, as yet, no evidence of the successful application of the principles of radar to train working. A form of radar is utilised in a few marshalling yards in the U. S. A. to determine automatically the speed of vehicles during shunting.

Appendix B.

Association of American Railroads.

RAILROAD RADIO GENERAL AND OPERATING RULES.

Adopted by the Federal Communications Commission on August 21, 1945, and attached to its Order No. 126 pertaining to operation of railroad radio equipment by railroad employees in connection with railroad operations.

General.

The following rules and requirements cover use of railroad radio systems and govern employees using such systems :

A. Definition : A Railroad Radio Com-

munication system is one employing radio for the transmission of intelligence between moving equipment, between moving equipment and a fixed point, or between fixed points.

B. Radio communication systems are under the jurisdiction of the Federal Communications Commission. The Railroad Company and its employees are governed by the Commission's operating rules. Violation is a Federal Offense for which severe penalties are provided.

C. In order to operate a radio transmitting set a railroad employee must read and study the following rules and pass an examination thereon. Such examinations will be given by railroad examiners.

Operating Rules.

1. All employees, except those specifically authorized to do so, are prohibited from making any adjustments to a railroad radio set. Employees so authorized must carry their FCC operator license or verification card when on duty. If it appears that a radio transmitter is not operating properly its use shall be discontinued and the designated railroad official notified as soon as possible.

2. No employee shall knowingly transmit any false distress communication, any unnecessary, irrelevant or unidentified communication, nor utter any obscene, indecent, or profane language via radio.

3. No employee shall divulge or publish the existence, contents, purport, effect or meaning of any communication (distress communications excluded) except to the person for whom the communication is intended or to another employee of the railroad whose duties may require knowledge of the communication. The above applies either to communications received direct or to any that may be intercepted.

4. Before transmitting any employee operating a radio transmitting set shall listen a sufficient interval to be sure that the circuit is not already in use, particularly for distress traffic.

5. A distress call will be preceded by the word « Emergency » repeated three times. Such calls shall be used only to cover initial reports of derailments, storms, washouts, fires, obstructions to tracks, or other matters which would cause serious delay to traffic, damage to property, injury to employees or the travelling public, and shall contain as complete information thereon as possible. All employees shall give absolute priority to communications from another station in distress, and except in answering or aiding a station in distress shall refrain from sending any communications until there is assurance that no interference will result to the station in distress.

6. The Railroad Company is required to answer an official notice of violation of the terms of the Communications Act of 1934, as amended, within three days from receipt of notice and any employee receiving inquiry concerning any violation shall answer such inquiry within 24 hours after receipt of notice.

7. Any employee shall permit inspection of the radio equipment in his charge and all FCC documents pertaining thereto, by a duly accredited representative of the Federal Communications Commission at any reasonable time.

8. Employees, except in yard operation, shall identify the radio station from which they are calling by prefacing their call with the railroad name, for example, « ABC (Railroad) Caboose Train 92 calling Engine », « XYZ (Railroad) Caboose Train 92 calling Engine Train 89 », or « MAIN (Railroad) Engine 547 calling Caboose 1402 ».

9. In certain cases at crossings, junctions or paralleling tracks some interference may develop with another railroad. In such cases especial care in making identification shall be used and the employees concerned

shall cooperate in handling their business by alternating calls and being as brief as possible.

10. If any communication from a station other than another railroad radio station interferes with Railroad Radio service the railroad employee will endeavour to ascertain the identity of such station and report the occurrence as soon as possible through authorized channels, to the designated railroad official, giving the exact time, nature of the communication and identity of the sta station, if possible.

Internationally, the word « MAYDAY » indicates a distress message, the word « PAN », an urgent message and the word « SECURITY », a safety message. Railroad employees may hear such messages sent by aircraft or in coastal areas, by boats. Railroad employees hearing such messages must report them immediately through authorized channels to the designated railroad official in addition to taking such appropriate action to relieve the distress as may be possible.

Appendix C.

Association of American Railroads.

(October 1952)

OPERATING TECHNIQUES FOR OPERATIONAL TRAIN RADIOTELEPHONE COMMUNICATION SYSTEMS.

A. — Definition of Systems.

A-1. A Train Radiotelephone Communication System is one which utilizes (1) Inductive Carrier, or (2) Radiotelephone, for the transmission and reception of intelligence between (*a*) front and rear ends of trains, (*b*) between trains, (*c*) between trains and way stations, (*d*) between way stations, (*e*) in yard and terminal service.

A-2. Where the term « way station » is used, it refers to other than mobile stations.

B. — Purpose.

B-1. The purpose of this section is to provide information which will serve as a guide to railroads using systems defined in A-1, in the preparation of Special or Supplemental Instructions to their employees to aid them in the use of such systems.

B-2. Of necessity such instructions must be drafted to meet the specific conditions and requirements of the type of equipment used on each railroad.

B-3. The general content would be substantially the same for both inductive carrier or radio systems. Railroad radio communications systems are under the jurisdiction of the Federal Communications Commission, railroads and their employees being governed by the Commission's Operating Rules. Way station personnel are required to be examined biennially on the General and Operating Rules agreed upon between the Federal Communications Commission and the Association of American Railroads. Personnel at mobile stations are required to be familiar with these rules but are not required to be examined. It is desirable then that these General and Operating Rules be set forth in the instructions issued by railroads using radio.

C. — Information in working timetable.

C-1. Territory and Way stations equipped with train radiotelephones should be designated in the working timetable.

D. — Use of train radiotelephone communication system.

D-1. The train radiotelephone system must be used only in connection with railroad business and protection of life and property.

D-2. Before transmitting, the man operating the train radio-telephone set shall listen a sufficient length of time to be sure that the channel is not already in use.

D-3. Speak into the transmitter with a clear, distinct tone of voice and slowly enough to be clearly understood.

D-4. No employee shall knowingly transmit any false distress communication, any unnecessary, irrelevant or unidentified communication, nor utter any obscene, indecent or profane language.

D-5. Way stations equipped with train radiotelephone will keep them turned « ON » at all times between initial and final terminals unless otherwise instructed.

D-6. Unless otherwise instructed, train and enginemen on engines and cabooses equipped with train radiotelephone must have the apparatus in service at all times between initial and final terminals.

D-7. After an engine has been attached to a train, a talk-test with the caboose or a way station shall be made before leaving the terminal. Satisfactory conversation between engine and caboose or way station shall serve as a test. Any failure will be reported immediately as provided in local instructions.

D-8. Employees using train radiotelephone in connection with train operations must satisfy themselves that they are in communication with the proper persons and must not consider conversation finished until the persons taking part are assured that they have heard all of the conversation and that it is understood, repeating same when necessary.

D-9. Persons using train radiotelephones must yield the train radiotelephone channel promptly for communications concerning train movements.

D-10. The train radiotelephone is to be used to report any irregular or unsafe conditions observed on trains or along right-of-way, and in any way that will benefit train operation, improve safety, or prevent accidents.

D-11. In Making a Call. Employees shall identify the train radiotelephone station from which they are calling by prefacing their call with the railroad name, repeating call at five second intervals.

Examples—

« N&S Caboose, Train 192 calling N&S engine, Train 192. »

« N&S Engine (or Caboose) 6789 east, calling CP Tower. »

« N&S Caboose, Train 77, calling N&S Caboose, Train 90. »

« N&S Engine 2345 calling Locust Street Yard Office. »

D-12. In Answering a Call. The railroad, train or engine number, caboose or station shall be used.

Examples—

« N&S Engine, Train 192, answering N&S Caboose, Train 192. »

« CP Tower answering N&S engine (or Caboose) 6789. »

« N&S Caboose, Train 90, answering N&S Caboose, Train 77. »

« Locust Street Yard answering N&S Engine 2345. »

D-13. In certain cases at crossings, junctions or paralleling tracks, some interference may develop with the train radiotelephone system of another railroad. In such cases, special care in making identification shall be used and the employees concerned shall cooperate in handling their business by alternating calls and being as brief as possible.

D-14. An « EMERGENCY » call shall be preceded by the word « EMERGENCY » repeated three times, then make announcement of any condition which might endanger the safety of a train, person, or structure along the right-of-way.

D-15. When « EMERGENCY » call is heard, all stations shall stand by. If the emergency is directed to a particular station or train, the party called will answer at once.

D-16. It is important that all train radiotelephone calls be answered promptly, as train accidents may be avoided by such action.

D-17. All failures of train radiotelephone units in mobile equipment and instances of inability to communicate with another train shall be reported as provided for by local instructions.

D-18. Personnel at way stations must promptly report to designated official all failures of train radiotelephone equipment to function properly, as well as instances of inability to contact equipped engines or cabooses.

D-19. The train radiotelephone must be turned « OFF » at the end of trip or as otherwise provided by local instructions.

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

16th. SESSION (LONDON, 1954).

QUESTION 8.

Determination of the principles of geographical and functional organisation of a railway system. Simplification and retrenchment of the administration of railways.

SUPPLEMENT TO REPORT (*)

by Bengt ADAMSON,
Superintendent, Swedish State Railways.

After the completion of our report, answers have been received from the following Administrations :

Indian Railways;
Iranian State Railways;
Irish National Transport Corporation;
South African Railways.

On the basis of these replies, certain additional statements are given below.

The modes of exercising the *ultimate control* are as follows :

Railway	*Method according to classification used in the report (page 579/7)*	*Notes*
Indian Railways	2	A Minister of Cabinet rank is in charge of Railways and the Railway Board functions under his direction.
Iranian State Railways .	5 (1) and 4 (2)	(1) The Railway High Council, composed of seven members, who will be appointed for a term of three years according to the proposal of the Minister of Roads and the approval of the Council of Ministers. The seven members include : a highgraded Engineer of the Ministry of Roads, 4 high officials of the State, a high official of the Ministry of Economic and a high official of the Ministry of Finance. (2) The Financial Supervisory Board composed of five members.

(*) See *Bulletin* for September 1953, p. 573.

Railway	*Method according to classification used in the report (page 579/7)*	*Notes*
Irish National Transport Corporation	5	The Board, composed of a full-time Chairman and six other members. The General Manager is a statutory officer of the Board.
South African Railways	3	The ports, harbours and railways of the Union of South Africa are, in terms of the South Africa Act, 1909, vested in the Governor-General-in-Council whose control and authority in the working of these undertakings are exercised through a Minister of State. The latter, who is designated the Minister of Transport, is advised by a board appointed in terms of the Act mentioned and known as the Railways and Harbours Board. This board consists of three commissioners appointed by the Governor-General-in-Council for a period of five years with the Minister of Transport as the chairman. In terms of the Railway Board Act, 1916, the management and working of the railways and harbours are, subject to the control of the Minister, carried on by the General Manager, whose authority is governed by such regulations as the Minister may, after consultation with the Railways and Harbours Board, frame from time to time in accordance with the provisions of that Act.

The arrangements for *determination of policy* and for *administrative control* are as follows :

Railway	*Method according to classification in the report (page 582/10)*	*Number of members (including chief or chairman)*	*Composition*
Indian Railways. . .	4	4	The Railway Board consists of three functional members one of whom is the Chairman and ex-officio Secretary to the Ministry of Railways and a Financial Commissioner for Railways, who is also an ex-officio Secretary to Govt. The three functional members are respectively in charge of Engineering, Transportation and Staff. The Secretary to the Govt. of India in the Ministry of Transport is also an ex-officio member of the Railway Board.

Railway	*Method according to classification in the report (page 582/10)*	*Number of members (including chief or chairman)*	*Composition*
			Below the level of the members of the Railway Board, there are Directors in charge of Civil Engineering, Mechanical Engineering, Railway equipment, Establishment, Finance and Budget. The Directors are assisted by a number of Joint, Deputy and/or Assistant Directors. The Directors issue instructions to Railways on policy matters and general matters pertaining to the subjects under their charge for implementing the decisions of the Board.
Iranian State Railways	1	4	The Board of Directors is composed of the General Manager (President of the Board and Legal Representative of the Administration) and three Assistant General Managers. (Technical, Financial and Administrative). The Assistants are appointed according to the proposal of the General Manager and the approval of the Minister of Roads. The General Manager is appointed with the approval of the Council of Ministers and according to the proposal of the Minister of Roads and the agreement of the High Council of the Administration.
South African Railways	1	6	The General Manager is assisted by a Deputy General Manager and four Assistant General Managers responsible respectively for the commercial, technical, operating and staff sections of the work. There is also a Chief Airways Manager. Each of the Assistant General Managers as well as the Chief Airways Manager is responsible under the general direction of the General Manager and the Deputy General Manager for the operation of his own branch or section and jointly they constitute with the Deputy General Manager a management committee under the chairmanship of the General Manager.

The *grouping of functions within Headquarters* is stated in chart 1 *a* in the corresponding way as in chart 1 of the report (p. 588/16).

As to *the grouping of functions within regional organs* it may be mentioned that the Iranian State Railways and the Irish National Transport Corporation combine

the operating and commercial functions.

The answer of the South African Railways may be quoted in certain parts as it shows a division of functions between different departments which seems to meet very well the desiderata, stated in point 5 *a-c* in the summary of the report.

« Each Region, which on the South African Railways and Harbours is called a System, is controlled, in the Transportation Department, by a system manager, who is responsible to the General Manager for the work of that department within his own territory.

A system manager controls, through his superintendents, engineers and other senior officers, etc., the working at stations, depots, running sheds, ports, harbours, road motor services, etc., in fact all the activities of the undertaking, except in cases where other departments are represented by local heads. Instances of the latter kind are the workshops of the Mechanical Department, which are locally controlled by a mechanical engineer. A system manager does not co-ordinate the working of different departments within his Region.

System managers are controlled directly by the General Manager through the General Manager's Department. The heads of other departments control the activities of their respective departments through local officers, e.g., the Chief Mechanical Engineer, who is the head of the Mechanical Department, controls the mechanical engineers; the Chief Accountant, who is the head of the Accounting Department, controls the local accountants, of whom there is one on each system. The Chief Mechanical Engineer, the Chief Accountant and other heads of departments are controlled by the General Manager, through the General Manager's Department.

The duties of each of the departments within a Region or system are as follows :

The Transportation Department (regional control exercised by a system manager).

Civil engineering, other than new construction work;
the maintenance of electrical equipment on lines and on rolling stock;
the maintenance of signalling equipment;
the working of traffic, including road motor and cartage services;
the provision of locomotive power and other rolling stock;
control of stations and locomotive shed staffs, including examination of and running repairs to locomotives and other rolling stock;
working and maintenance of harbours and lighthouses;
commercial activities.

The Civil Engineering Department (regional control exercised, in the case of new construction work, by a resident engineer, otherwise by a system manager).

Direct control of new construction work. This Department prescribes the standards on which lines, works, etc., shall be maintained and renewed, the actual carrying out of the work being the responsibility of the system engineers, who are controlled by the system managers. To co-ordinate the practices on the various systems and also to satisfy himself as to the safety and efficiency of the line as a whole, for which he is responsible, the Chief Civil Engineer has inspecting engineers who report to him on such matters.

The Mechanical Department (regional control exercised by a mechanical engineer).

The construction of locomotives and other rolling stock, and the maintenance of workshop machinery and plant generally, as well as giving technical guidance in connection with running repairs done by the Transportation Department.

The Accounting Department (regional control exercised by a local accountant).

The receipt of revenue from, and the payment of accounts incurred by, all departments; payment of salaries and wages.

The Stores Department (regional control exercised by a stores superintendent).

The acquisition and issue of stores and materials needed by the various departments.

The Signals Department (regional control exercised by a system manager).

The renewal and maintenance of signals are directly controlled by a signal engineer on the staff of the system manager concerned, but the Chief Signal Engineer exercises overall technical control through his engineering staff.

Any major construction programme is undertaken by the staff of the Chief Signal Engineer.

Electrical Department (regional control exercised by a system manager).

In this department the position is broadly similar to that in the Civil Engineering and Signals Departments.

Catering Department.

Regional control is exercised by a district catering manager. The duties are those connected with the control of dining-car services and refreshment-rooms.

Publicity and Travel Department.

Regional control is usually exercised by a publicity and travel agent. The work undertaken is the running of bookstalls, advertising and arranging tours. »

As to the different *types of territorial division* the table on page 594/22 in the report could be completed as follows :

Type of territorial division	*Railways applying the type mentioned in the first column*	*Size of railways*	
		Length of line operated, km	*Number of staff*
1 *a)* The territorial units come directly under Headquarters. The organisation is of *departmental* type	Irish National Transport Corporation	3 300	13 000
1 *b)* The territorial units come directly under Headquarters. The organisation is of *divisional* type	Iranian State Railways	2 600	24 000
	South African Railways	21 600	155 000

The Indian Railways are divided on a divisional basis into 6 zones, each headed by a General Manager. The organisation in some of these zones are of divisional type, in others of departmental type. The whole system embraces 53 600 km lines operated and a staff number of 925 000.

As regards the *size of divisional units* (table on page 598/26 in the report) it can be noticed that the South African Railways would come at the top of the table with an average length of line per territorial unit of 2 394 km (1 488 miles).

The *discussion of the principles of departmental and divisional organisation* can be completed with the following statements given by the Indian Railways, which have both types of organisation.

« This system (*divisional organisation*) ensures co-ordination between the local functional officers, but functional control from the top is indirect and, therefore, weaker. »

« This system (*departmental organisation*) provides for direct control of the regional officers by their respective functional or departmental chiefs, but there is no co-ordinating authority below the level of the General Manager. When the zone is big such lack of co-ordination leads to delay and inefficiency. »

« Both systems have been in vogue on Indian Railways and have worked satisfactorily. With the recent integration of Indian Railways into such larger systems, it is yet to be seen how the organisation described under item 20 (*departmental organisation*) will stand up to new demand on it. »

This declaration seems to confirm the statement made in the report, that the development within larger railway systems seems to tend towards organisations of a divisional type.

Finally, the following statements can be given, completing the table on page 605/33 in the report :

Railway	*Number of personnel*			*Percentage of total personnel*			*Traffic units during one year (millions)*
	Head-quarters	*Other mana-gerial units*	*All system*	*Head-quarters*	*Other mana-gerial units*	*Col 5 + 6*	
1	2	3	4	5	6	7	8
Irish National Transport Corporation (C.I.E.)	398	82	13 081	3.0	0.6	3.7	749
South African Railways	867	6 367	154 880	0.6	4.1	4.7	Not available

CHART 1 *a.* — **Grouping of functions within Headquarters.**

Railway	*Irish National Transport Corporation*	*Iranian State Railways*	*South African Railways*	*Indian Railways*
Headquarter functions are divided into the following groups :	1. Traffic Accountancy 2. Motive Power 3. Civil Engineering 4. Signal & Electrical Engineering 5. Mechanical Engineering 6. Stores 7. Staff relations 8. Public relations 9. Secretary 10. Medical matters 11. Road motor Engineering 12. Hotels	1. Operation Motive Power and Mechanical Engineering, Civil Engineering, Signal, Electrical and Telecommunications Engineering 2. Finance Accounts Purchases 3. Personnel and Social matters Medical matters Police *Note:* In addition there also exists a General Secretariat, an Accident Section, a Technical Statistics and Research Section, an Inspection Section and an Administrative Court.	1. Operation 2. Commercial 3. Technical 4. Staff 5. Airways	1. Transportation 2. Engineering 3. Staff *Note:* Each of the 6 zones, in which the system is divided, has a General Manager, assisted by Headquarters. In those Headquarters a more far-going division of functions is applied.
Total number of employees	13 100	24 000	154 900	925 300

[621 .135 .4, 625 .143 .3 & 625 .215]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

16th SESSION (LONDON, 1954).

QUESTION 10.

Wear of rails on curves :

a) running effects of locomotives and motor coaches with motor bogies;

b) characteristics of track-laying on curve and details of the rolling stock liable to cause premature wear of the rails;

c) results of the investigations made and proposed remedies. Use of rail-lubrication processes.

REPORT

(Austria, Belgium and Colony, Bulgaria, Czechoslovakia, France and French Union, Germany, Greece, Hungary, Italy, Luxemburg, Netherlands, Poland, Portugal and Colonies, Rumania, Spain, Switzerland, Syria, Turkey and Yugoslavia),

by L. Ripert,

Ingénieur en Chef,

Chef du Service de la Voie et des Travaux de la Société Générale des Chemins de fer Economiques (France).

Twenty-six of the sixty-six Administrations consulted have supplied information (Table I). Ten of the railways operated by these Administrations are of purely standard gauge; ten are of metre gauge and the remaining six have standard or wide gauge and metre gauge.

The replies of several Administrations exceed the scope of Section V, but they have nevertheless been used because of the importance of their contribution to the study of the question.

The arrangement adopted in this Report is not exactly as it was in the Questionnaire; in particular, while the questions relating to the effects of the use of motor bogies were at the beginning of the Questionnaire owing to their topical character, it has seemed more logical to put this study after the considerations on the influence of the characteristics of curved track and of the features of the rolling stock.

The Report comprises three parts, with some preliminary general observations.

Preliminary general observations.

General notes on the types of rail wear;

Observations on the form of profiles of worn rails;

Curves in which lateral rail wear is noticed;

Condition of worn surfaces;

Particular types of rail deformation; deformation and longitudinal cracks in the web.

I. *Characteristics of the laying of curved track and features of rolling stock liable to cause premature wear of rails.*

A. *Influence of the characteristics of the track :* lay-out, superelevation, parabolic curves, gauge, cant of the rail, gradients, joints, types of sleeper, fastenings and spacing, climate and atmospheric conditions.

Wear of rails in switch curves.

B. *Influence of certain features of rolling stock :* wheelbase, play which increases the obliqueness of the axle to the guiding rail, tyre profiles, wheel diameter, effects of oscillation due to the position of loads, operating resistance of bissel trucks and bogies, influence of the suspension; various influences.

II. *Effects of the operation of locomotives and rail motor coaches with driving bogies.*

Development of machines with driving bogies;
Principal arrangements;
Comparison between the various motive units and vehicles in relation to wear of rails :
effects of driving bogie vehicles compared with motive units and vehicles with rigid wheelbase;
effects of driving bogies compared with non-driving bogies;
classification of vehicles in order of decreasing influence on wear of rails in curves;
causes of increased wear of rails due to driving bogies.

III. *Results of investigations and remedies envisaged.*

A. *Results of the investigations :* nature of the investigations; gauges used; relationship between wear noticed and the various causes; causes of excessive cant on rail tread; modifications in the structure of the metal; permissible limits of wear before withdrawal of the rails.

B. *Remedies adopted, tried, or under consideration for reducing the wear of rails on curves :*

1) modification of certain track laying regulations;

2) maintenance procedure — re-turning of rails;

3) laying of a check rail along the inner line;

4) use of rails with a high resistance to wear;

5) lubrication of rails; description of procedure and equipment :
maximum radius of curve lubricated;
materials used for lubrication;
advantages and disadvantages of materials and methods used;
maintenance costs of various appliances and annual charges;
results obtained.

Conclusions.

PRELIMINARY GENERAL OBSERVATIONS.

Wear of rails due to the action of wheels presents special features on curved track and their replacement must, in general, be undertaken at a more rapid rate than with rails located on straight sections.

Study of the effects noticed, their causes and the remedies which it is possible to effect is therefore of major importance in the maintenance of track with a sinuous lay-out.

General notes on types of rail wear.

It is appropriate to distinguish between the wear on a line of rails of *large radius* (outer or higher rail) and that on a line of rails of *small radius* (inner or lower rail).

1) Wear on the head of the *large radius* rail is the most characteristic and the most severe. It occurs generally in two forms :

a) the inner face of the rail is subject to *lateral chamfering wear*;

b) the running surface is frequently subject to wear on a surface inclined towards the interior of the track, thus producing an excessive *cant* of this surface.

2) The wear on the head of the *small radius* rail is a *flattening of the running surface*, almost parallel to it. This is often accompanied by a spreading of the metal

Standard gauge

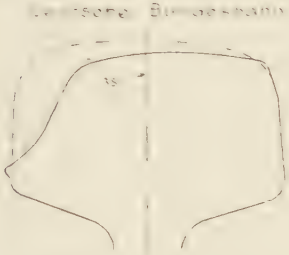
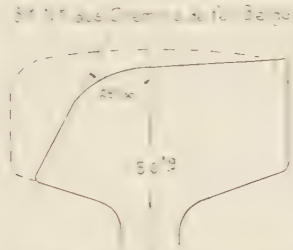
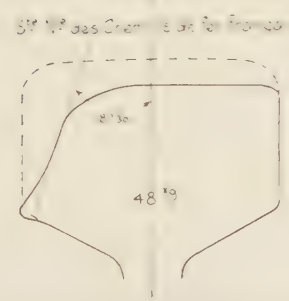
	LINES	*Radius of curve*	*No. of years rail has been in service*	*Weight of the heaviest axles*	*Average daily number of axles*
	*Siegen-Hagen*	430 m	12	20 t	—
	Steyr-Hieflau	200 m	—	20 t	
					
	*Clermont-Ferrand-Montbrison*	300 m	env. 40	17 t	300

Fig. 1. — Profiles of worn rails (*outer large radius line*).

Standard gauge

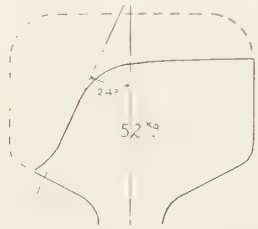
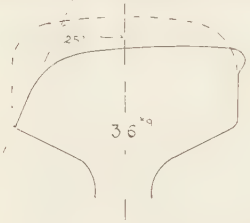
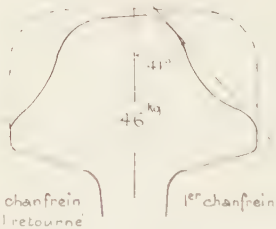
	LINES	*Radius of curve*	*No. of years rail has been in service*	*Weight of the heaviest axles*	*Average daily number of axles*
Regie Autonome des Transports Parisiens. 	*Réseau Urbain* . . .	75 m	env. 8	15 t	
Chemins de fer Italiens de l'Etat 	*Rome-Sulmona* . . .	300 m	67	16 t	650
C.ie des Chemins de fer Portugais		350 m	40	14 t	
Chemins de fer fédéraux Suisses 	*St-Gothard (Lavorgo-Giornico)* .	300 m	2.5	20 t	

Fig. 1. — Profiles of worn rails (*outer large radius line*).

N. B. — 2e chanfrein rail retourné = 2nd chamfer re-turned rail. — 1er chanfrein = 1st chamfer.

Metre gauge

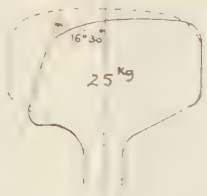
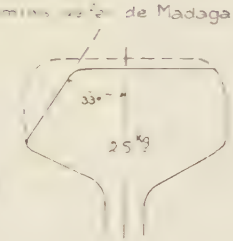
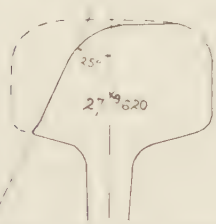
	LINES	*Radius of curve*	*No. of years rail has been in service*	*Weight of the heaviest axles*	*Average daily number of axles*
Cie des Chemins de fer Tunisiens. 	*Tunis-Kalaa-Djerda* . .	150 m	8	14 t	20 trains
Chemin de fer Franco-Ethiopien. 	*Djibouti-Addis-Abéba* .	100 m	43	10 t	235
Chemins de fer de Madagascar. 	*Tananarive-Tamatave* .	50 m	25	11.5 t	362
Chemin de fer de Damas à Hama. 	*Damas-Hama*	100 m	25	13 t	

Fig. 1. — Profiles of worn rails (*outer large radius line*).

to form a burr on the inner or the outer edge, or even on both. More rarely, the inner face also develops a chamfer. Sometimes the running surface hollows slightly to give a concave shape.

The actual wear of rails being dealt with individually, the question of undulating wear does not arise.

profiles which are the most characteristic of those submitted (fig. 1 and 2). An examination of them allows the following observations to be made :

1) the section of lateral chamfering is most often a straight line with an angle of inclination from the centre line of the rail varying between 13° and 45°, the values

Fig. 1*bis*. — Profile of worn rail (*Netherlands Railways*).

Radius of curve	350 m (382 yards)
Number of years in service	13
Weight of the heaviest axles	25 t

Observations on the forms of profile of worn rails.

In view of the impossibility of reproducing all the drawings which have been supplied, it has been necessary to select a few

noted being frequently between 20° and 30°. This angle almost corresponds to that of the face of the wheel tyre in contact with the rail;

2) the section of the running surface is

nearly a straight line, sometimes inclined at an angle of 3° to 8° from a perpendicular to the rail centre line;

3) these two lines are connected by a concave radius which is often less than that of the edge of the head when new;

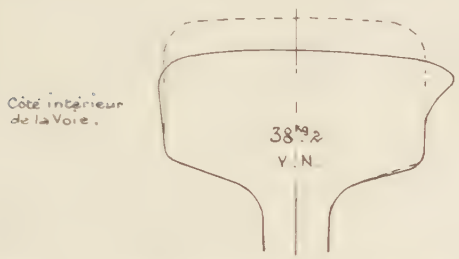


Fig. 2. — Rail of the inner, smaller radius curve (*Tunisian Rys*). — R = 300 m (328 yards).

N. B. — Côté intérieur de la voie = inner side.

Fig. 2*bis*. — Rail of the inner, smaller radius curve (*Rhaetian Rys*).

4) when wear is very heavy, the chamfer has a curved shape, concave towards the top, the versine of which may be up to 2 to 4 mm (0.078 to 0.157 in.) (particularly with rails of the German Federal Railways, Austrian Federal Railways, Swiss Federal Railways and Rhaetian Railways).

A study of the profiles of the same rail, undertaken by the Swiss Federal Railways on successive dates, shows the development of the wear, on a line with heavy traffic density (fig. 3). The upper radius of the head is first attacked and produces an almost rectilinear chamfer. The wear increasing more, the face of the head in contact with the flange assumes a form concave towards the top, as mentioned above. If the rail is turned, the worn section of the head becomes a rough truncated cone in shape.

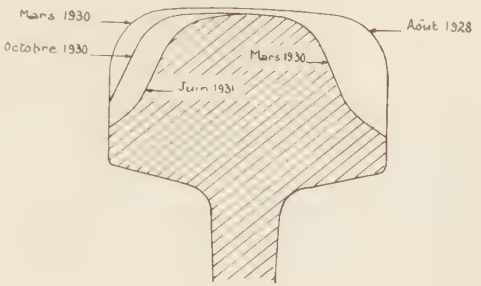


Fig. 3. — Development of rail wear (*Swiss Federal Rys*).

N. B. — Mars 1930 = March 1930. — Octobre 1930 = October 1930. — Juin 1931 = June 1931. — Août 1928 = August 1928.

Curves in which lateral wear of rails is found (Table I).

a) On standard gauge lines, the current minimum radius varies from 350 to 250 m (383 to 273 yards), exceptionally from 300 to 150 m (328 to 164 yards). In the special case of the R.A.T.P. (Paris Metro) the values of these radii drop to 75 and 30 m (83 and 33 yards) respectively.

The radius from which lateral wear is experienced varies, according to the Railway, between 1 200 and 300 m (1 312 and 328 yards); it is particularly noticeable below 500 m (547 yards).

The Austrian Federal Railways state that the radius R is a function of the speed of operation, taking the equation :

$$\frac{R}{V} = 10.$$

V being expressed in km/h.

b) On metre gauge lines, the current minimum radius varies from 300 to 120 m (328 to 131 yards) (on certain lines to 80 m [87 yards]). Exceptionally it is from 200 to 40 m (219 to 44 yards). That from

TABLE I.

Administrations	Standard (or wide) gauge			Metre gauge		
	Minimum radius		Radius R (1)	Minimum radius		Radius R (1)
	standard	exceptional		standard	exceptional	
GERMANY						
Deutsche Bundesbahn . . .			700			
AUSTRIA						
Austrian Federal Railways.	350	180	R = 10V	—	—	
BELGIUM and COLONY						
Sté. Nle. des Chemins de fer Belges	350	200	1 200	—	—	
Office d'Exploitation des Transports Coloniaux (Matadi-Léopoldville)				250	140	300
FRANCE and FRENCH UNION						
Sté. Nle. des Chemins de fer Français (certain secondary lines)	300	150	1 000 (2)	80	—	
Sté. Générale des Chemins de fer Economiques	300	150	450	200	150	300
Chemins de fer Economiques du Nord	—	—	—	125	40	300
Régie Autonome des Transports Parisiens — Réseau Urbain. . .	75	30	1 000 (3)	—	—	—
Régie Autonome des Transports Parisiens — Lignes de banlieue .	250	220	1 000	—	—	—
Compagnie Générale des Voies Ferrées d'Intérêt Local. . .	250	150		150	100	300
Chemins de fer Algériens . .	250	200	300	150	100	300
Chemins de fer de Gafsa . .	—	—	—	300	200	350
Compagnie fermière des Chemins de fer Tunisiens . . .	500	250	400	250	150	300
Chemins de fer de l'Afrique Equatoriale Française & du Cameroun	—	—	—	150	120	300
Chemins de fer coloniaux de l'Afrique occidentale française et Togo	—	—	—	120	100	250
Chemin de fer franco-éthiopien de Djibouti á Addis-Abeba	—	—	—			300

TABLE I *(Continued)*.

Administrations	Standart (or wide) gauge			Metre gauge		
	Minimum radius		Radius R (1)	Minimum radius		Radius R (1)
	standard	exceptional		standard	exceptional	
FRANCE AND FRENCH UNION *(continued)*						
Chemins de fer de Madagascar	—	—	—	120	50	150
Chemins de fer du Maroc . .	800	350	700	—	—	—
Chemin de fer de la Méditerranée au Niger	500	300	300	—	—	—
Régie des Chemins de fer non concédés du Viet-Nam . . .	—	—	—	300	100	200
ITALY						
State Railways { normal.	800	350	500	300	70	—
State Railways { mountain. . . .	400	200			40	
LUXEMBURG.						
Sté. Nle. des Chemins de fer Luxembourgeois.	350	180	1 000			
NETHERLANDS						
Netherlands Railways. . . .	500	300	tous	—	—	—
PORTUGAL.						
Portuguese Railways Cy . .	300	250	700	100	60	200
SWITZERLAND						
Federal Railways	300	100	800	—	—	—
Rhaetian Railways	—	—	—	120	100	250
SYRIA						
Damas - Hamah Railway . .	300	180	300	100	90	120

(1) R = Radius at which the lateral wear of the rails becomes noticeable.

(2) particularly noticeable after 500 m (547 yards).

(3) particularly noticeable after 300 m (328 yards).

which lateral rail wear becomes manifest varies between 350 and 120 m (383 and 131 yards).

Condition of worn surfaces.

The surface finish of rails and wheel tyres is most often maintained, at least when the surfaces are relatively little used, or if, as a result of increased wear, they are suitably lubricated.

Binding is sometimes experienced during the passage of pair of wheels; it is shown particularly in the following ways :

— *grinding* is noticed on most systems, especially in curves of less than 300 m (328 yards) radius;

— the *dropping of scrapings* on the foot of the rail in curves of very low radius is frequently observed;

— *long straight strips* are detached from the lateral face of the head of the upper rail (Algerian and Austrian Federal Railways). The Swiss Federal Railways state that, if the lubrication of the surfaces is insufficient, or is completely lacking, a tearing is experienced, the shavings reaching 5 × 5 × 0.5 mm (0.196 × 0.196 × 0.019 in.) the side of the rail and of the flange then having the appearance of a rasp.

On the Cameroons Railways, when traction was wholly by steam, very fine scrapings were found in curves of 250 to 120 m (273 to 131 yards) radius, whilst since the introduction of diesel locomotives, irisated spills of 2 to 5 mm (0.078 to 0.196 in.) in length are formed.

On the lines of the Paris Metro (R.A.T.P.), if lubrication is insufficient, the wheel flanges bind on the side of the head, producing foliated patches of metal; the condition deteriorates very rapidly.

Variations of lateral wear along the rails of a curve.

Variations are sometimes noticed in lateral wear along the rails of a curve; they are greater when there are more irregularities of curvature in the track. Wear is often less at the joints than towards the middle of the rails.

The Cameroons Railways report that they increase from the tangent point to the top of the curve.

On the Paris Metro, they show themselves particularly at the two ends of the curves because of the inadequacy of the transition.

Particular types of rail deformation.

a) Deformation of the web of the rail, by bending its vertical centre line towards the outside of the track, is often noticed. This bending generally varies from the joint to the centre of the rail.

The Damas-Hamah attribute this to the difficulty with which some vehicles inscribe the curve. The Algerian Railways have noticed it, especially in the neutral section and along the full length of the rail; also by the Cameroons Railways, in exceptional cases, caused by heavy corrosion of the metal. The Portuguese Railways are seeking to eliminate this bending by fitting wooden wedges against the outside of the web of the rail.

b) Longitudinal cracks in the web in a horizontal direction are rarely noticed apart from those which may arise near fish-plate bolt holes and which are not peculiar to rails worn laterally. The Belgian National Railways have however found an average of 24 per year during the last four years. The Damas-Hamah Railway has observed them in curves of 100 to 120 m (109 to 131 yards) radius (metre gauge) on both lines of rail, level with the fixing of the shoe, and the full thickness of the web. The Cameroons Railways report a similar case. The Algerian Railways have found them immediately under the head, but more frequently in the upper fishing surface. The Portuguese Railways state that these cracks are produced inside and outside the track, about the same height of the web, their depth varying from 2 mm (0.078 in.)

(R = 500 m) to 8 mm (0.314 in.) (R = 350 m).

I. — CHARACTERISTICS OF THE LAYING OF CURVED TRACK AND FEATURES OF ROLLING STOCK LIABLE TO CAUSE PREMATURE WEAR OF RAILS.

A. — Influence of the characteristics of the track.

Influence of the lay-out.

a) Relationship between wear and curvature. — Lateral wear of the rail increases as a function of the curvature. This fact is generally remarked but no Administration appears to have established a precise relationship between the amount of wear and the radius of curvature.

The French National Railways state that with the P.L.M.A. 34 kg (75 lbs.) rail, which has a very shallow head on which wear is almost rectilinear, it is found that wear is twice as much in a 300-400 m (328 to 437 yards) curve as in an 800 m (875 yards) curve. It would, therefore, in this case be in almost inverse proportion to the radius. This is also the opinion expressed by the Moroccan Railways.

The Railway Research Bulletin of July 1937 states in this respect that this wear is probably inversely proportional to the square of the radius; thus, in a curve R = 430 m (470 yards), it would be 16 times as great as in a curve R′ = 4 × 430 = 1 720 m (1 881 yards).

The Tunisian Railways provide the following information for the 25 kg (55 lbs.) rail used on metre gauge track which carries a traffic of 8 000 to 10 000 tons gross per day :

R = 150 m (164 yards), life of rail 8 years;
R = 250 m (273 yards), life of rail 20 years;
R = 300 m (328 yards), life of rail 30-35 years.

Thus, with twice the radius, the life is quadrupled, which confirms the ratio expressed above.

On the other hand, the Rhaetian Railway (metre gauge, operating 30-60 trains per day) find that the life of rails increases less rapidly than above in relation to the radius :

R = 100 to 150 m (109 to 164 yards), life of rail 25-30 years;
R = 150 to 200 m (164 to 219 yards), life of rail 30-35 years;
R = above 200 m (219 yards), life of rail 35-50 years.

The Swiss Federal Railways note that, in their experience, rails from the same suppliers and of identical manufacture, put into service at the same time in curves of similar radii, located on the same gradient and subject to the same traffic, offer different wear. They consider that to establish a theoretical relationship between the degree of wear and the radius of curvature, it would be necessary to have a sufficiently large number of measurements to bring into effect the law of large numbers.

b) *Influence of irregularities of curvature.*

Several Administrations consider that irregularities of curvature, being connected from time to time as they arise, have no appreciable influence on the wear of rails. Others are of the opposite view : certain of them add the following information :

On the Austrian Federal Railways, lateral wear is heavier and more irregular when the difference between the two neighbouring versines is greater than

$$150 \frac{S}{V}$$

(S being the length of the chord and V the speed in km/h, which gives for example 30 mm (1.18 in.) when S = 20 m (22 yards) and V = 50 km (31 miles)/h.)

The French National Railways state that variations of ± 15 mm (0.590 in.) on a chord of 20 m do not appear to have any marked incidence on the secondary lines surveyed. Comparison of graphs compiled

from versines measured and the lateral wear of corresponding rails shows that a *localised* increase in the versine, particularly at joints, corresponds to a zone of reduced rail wear. The Cameroons Railways state, on the other hand, that wear is heaviest at points where the versines are greatest.

The amount of versine variation above which wear is noticeably increased, is computed at 20 % for radii less than or equal to 80 m (87 yards) on the Madagascar Railways.

The Franco-Ethiopian Railway mentioned that wear is increased from 4/10 to 5/10 mm (0.0157 to 0.0196 in.) when the versines vary :

— from 1.5 to 2 mm per m (0.059 to 0.078 in.) for R between 120 and 150 m (131 and 164 yards);

— from 3 to 3.5 mm per m (0.118 to 0.138 in.) for R between 200 and 250 m (218 and 273 yards)

and that the increase is less marked when R = 300 m (328 yards) and is negligeable when R = 400 m (437 yards).

The Swiss Federal Railways give as example two curves of 300 m radius, situated on down grades of 26 and 27 mm m (1.02 and 1.06 in./yard) of which the variations in radius recorded were respectively 296 to 304 mm (11.65 to 11.96 in.) (or ± 1.3 %) and from 254 to 346 mm (10 to 13.62 in.) (or ± 15.3 %). Moreover, in the first curve, the better aligned, wear varied relatively little along the same rail

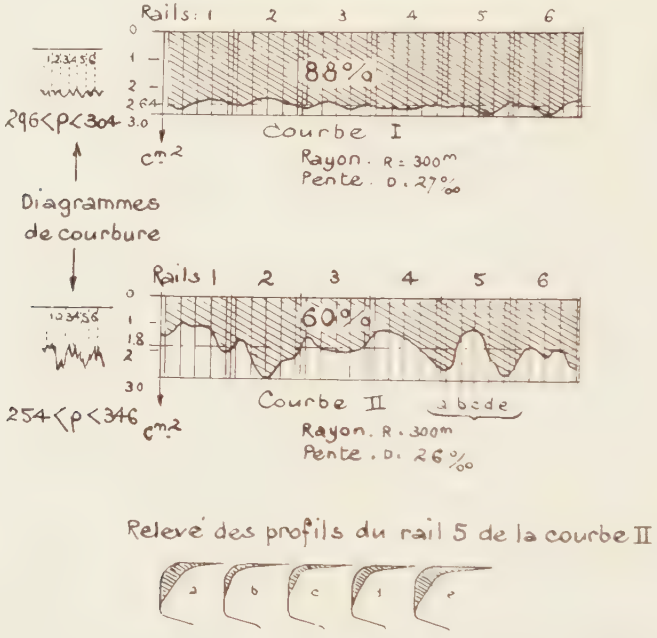


Fig. 4. — Variations of lateral wear in rails of two curves of 300 m radius showing different amounts of irregularity of curvature (*Swiss Federal Rys*).

Explanation of French terms:
Diagrammes de courbure = diagrams of curvature. — Rayon = radius. — Pente = gradient. — Courbe = curve.

and its measured average was 88 % of the permitted limit; in the second curve, variations of wear were greater, but the measured average was only 60 % of the permitted limit (fig. 4). The differences can be explained by the lateral oscillations which the irregularities of alignment cause on vehicles.

Finally it may be noted that the *length of rails* is a factor bearing on the wear, the use of short lengths making difficult the maintenance of correct alignment on curves of small radius.

Influence of superelevation.

For a curve of given radius, the amount of superelevation has a basic influence on the effect of rail wear according to the speed of the trains running over it. It therefore seems useful to recall the formulae used to establish the superelevation and then to consider the effects of insufficient or excessive provision.

a) *Formulae used to establish superelevation.*

All the formulae used give superelevation values inversely proportional to the radius of the curve and, for the most part, they are proportional to the square of the speed of operation.

The equations which show that the resultant of the weight and the centrifugal force is normal to the plane of the track are quoted below :

for standard gauge : $D = \frac{11.8\ V^2}{R}$;

for metre gauge : $D = \frac{8.2\ V^2}{R}$.

Where these formulae are used, the values of V taken are either :

— the speed of slow trains which are predominant (Gafsa, Tunisian for the V.M.);

or — the maximum speed, if it is that of most trains (« Régie Autonome des Transports Parisiens », Urban services);

or — an intermediate speed, which is the most frequent case; for example the French National Railways habitually use a superelevation of $\frac{C}{R}$ in which C frequently takes into account an intermediate speed. A basis is sometimes taken of :

$$V = \frac{2}{3} V_{max} + 5.$$

Various formulae are derived from those above :

— Swiss Federal :

$$D = \frac{8\ (V + 5)^2}{R} \quad \text{(standard gauge)}$$

in which V varies from 50 to 100 km (31 to 62 miles)/h, following which R varies from 175 to 580 m (191 to 634 yards);

— German Federal, Austrian Federal, Luxemburg, Netherlands Railways : on lines where the speed of trains varies with their nature :

$$D = \frac{8\ V^2}{R} \quad \text{(standard gauge)}$$

V being the average speed of trains and railcars; on lines of the first three Administrations above, where the speed of all trains is practically the same, the following theoretical formula is applied :

$$D = \frac{11.8\ V^2}{R}.$$

Several Administrations use a formula of linear variation as a function of V :

— Portuguese Railways (who have another formula under consideration);
— « Compagnie Générale des Voies Ferrées d'Intérêt Local » :

$$D = \frac{V}{R};$$

— Algerian Railways :

standard gauge : $D = \frac{V - 25}{R}$ for $V < 75$,

and $\frac{1.6\ V - 15}{R}$ for $V > 75$;

metre gauge : $D = \frac{0.73\ (V - 25)}{R}$.

b) *Effects of excessive superelevation.*

During the passage of heavy and slow trains, the absence of any effective centrifugal force has the effect of putting a greater portion of the load on the lower rail than on the upper rail; the excess load on the lower rail, disregarding centrifugal force, has a value of :

$$P \frac{h}{e} D,$$

P being the axle load, h the height of the centre of gravity, above the running surface, D the superelevation and e the gauge of the track.

For example, when P = 18 000 kg (39 683 lbs.), h = 2 m (6′ 6 3/4″), D = 0.10 m (3 15/16″), e = 1.50 m (4′ 11 1/16″), the overload is 2 400 kg (5 291 lbs.).

The excess superelevation results in bruising the head of the inner rail and sometimes in tearing the metal and the formation of burrs.

c) *Effects of insufficient superelevation.*

Lateral acceleration without compensation by superelevation has a value of :

$$\frac{V_{max}^2}{12.96\ R} - \frac{D \times 9.81}{e}$$

or, for standard gauge, expressing D in mm :

$$\frac{V_{max}^2}{12.96\ R} - \frac{D}{153}\ (^1).$$

The permitted values on the German and Austrian Federal Railways for uncompensated lateral acceleration is 0.65 m/sec² (2′ 1 5/8″ sec²). It is 0.50 (1′ 7 11/16″) on the Tunisian Railways.

Maximum amounts of superelevation are generally 150 or 160 mm (5.90 or 6.30 in.) for standard gauge and 100 to 120 mm (3.93 to 4.72 in.) for metre gauge.

Insufficient permitted degrees of superelevation resulting at maximum speeds vary, for standard gauge from 60 to 150 mm (2.36 to 5.90 in.) according to the lines and the nature of the traffic (for example 100 mm [3.93 in.] for Diesel and steam locomotives and 150 mm [5.90 in.] for railcars on the Tunisian Railways). For metre gauge, the permitted inadequacies vary from 70 mm (2.75 in.) (Diesel and steam) to 100 mm (railcars).

The influence of insufficient superelevation is mainly on the chamfer wear of the outer rail.

Influence of transition curves.

Insufficiently long parabolic curves, the consequent excessive superelevation rise and irregularities from warping of the track have, on the majority of systems, an influence on the lateral wear of rails.

On the urban system of the « Régie Autonome des Transports Parisiens », the conditions for siting structures do not generally allow curves to be of sufficient length and superelevation slopes, which moreover reach 4 mm (0.157 in.) per metre are longer than the curves; this results in the creation of irregular lateral wear.

Irregularities from warping of the track cause successive over- and under-loading of wheels increased by dynamic effects which grow with the speed (Algerian, Swiss Federal Railways) and irregular chamfering of the rails (Moroccan Railways). The Franco-Ethiopian railway has been unable to find that irregularities in the region of 1.6 mm (0.062 in.) per metre have any influence on the wear of the rails.

On the other hand, when the length of the curves can be obtained in relation to the permitted variations of superelevation (1.5 to 3 mm/m [0.058 to 0.118 in.]) according to the lines, for speeds going up to 80 km (50 miles)/h, on certain secondary lines of the French National Railways, a considerable linear variation in lateral wear is noted from the exit from the straight section to the entrance to the curve.

The Tunisian Railways, who limit on

(1) See Report by BAUMANN and JAEHN on Question 3, 2nd Session. — Cairo Congress, 1933. *Bulletin*, December 1932, p. 2251.

their main lines (speeds 100 to 120 km [62 to 74 miles]/h) superelevation slopes to 1 mm (0.039 in.) per metre for standard gauge and 0.7 mm (0.0275 in.) per metre for metre gauge, and who reduce speeds wherever these conditions are not met, consider that these dimensions (fixed to avoid uncompensated acceleration and excessive frame distortion) contribute to reducing to a minimum the wear of rails on curves.

The Italian Railways, which adopt superelevation slopes varying as a function of the speed from 1 to 2 mm (0.039 to 0.078 in.) and exceptionally 3 mm (0.118 in.) per metre state that this has not caused any abnormal lateral wear.

Influence of the gauge.

Track generally has a widening which is greater as the radius falls (maximum : 35 mm [1.37 in.] for standard gauge and 25 mm [0.98 in.] for metre gauge). It is now admitted that slacks designed to allow vehicles to take curves are often exaggerated, because they result in excessive angles of attack which contribute to an increase in the lateral wear of rails.

The metre gauge track of the French Light Railways, which is laid without slacks, does not experience particularly heavy rail wear.

The French Light Railways of the North and the Rhaetian Railway state that abnormal wear is a sign of excessive widening.

The Swiss Federal Railways, on the basis of investigations carried out by the «Verein Mitteleuropäischer Eisenbahn-Verwaltungen » have since 1940 reduced from 20 to 10 mm (0.787 to 0.39 in.) the slacking of curves with 275 to 325 m (300 to 355 yards) radius. Inscription of vehicles has thus been improved and wear of the outer rails has been reduced.

With small radii, however, insufficient width for the vehicle wheelbase can be a cause of increased rail wear. Thus, the Cameroons, Madagascar and Viet-Nam Railways state that wear is more rapid if the gauge is too much reduced. For this reason, the German Federal Railways, who have found that on curves laid with slacks lateral wear is more by 10 % to 15 % than on curves without slack, have discontinued it for radii less than 300 m (328 yards).

With regard to variations in gauge, the French National Railways state that in a given curve, differences of less than 10 mm (0.393 in.) do not appear to have any appreciable influence on lateral wear.

Influence of faults in the cant of the rail.

On all Railways, rails are laid with an angle inclined from the vertical (generally 1/20th, in several cases 1/18th; on the German Federal Railways 1/40th is reported for some lines). This inclination is practically invariable in the case of bull-head rails with chairs (French National and Light Railways). It is often the same in the case of flat-bottom rail laid on metal sleepers; at the same time, the Franco-Ethiopian Railway reports some relatively large angles of inclination.

When rails are laid on wooden sleepers, without soleplates, the rail cant which is produced, if the fixings are not sufficiently tight, cause a widening of the gauge. If this is rectified quickly enough during maintenance it has no influence on lateral wear. Otherwise, it has the effect of increasing lateral wear and of tilting the running surface of the outer rail; it may cause vehicles to hunt (Italian State Railways).

Influence of gradients.

On several railways, no special note has been made of this subject; on single-track lines, moreover, it is often difficult to distinguish between up and down gradients.

On *up-gradients*, trains often operate at a speed which does not correspond to the superelevation, which causes increased wear on the inner rail. In addition, too sharp accelerations can cause shocks to the large radius rail by the wheel flanges and the skidding may produce localised wear.

On *steep down-gradient curves* wear is more rapid than on *up-gradients*. It

appears that this may be attributable above all to the increased speed and braking of the trains. Creep of the rails, closing up the joints, may give rise to deformations which cause abnormal wear (French Light Railways). The Swiss Federal Railways consider that under the effect of braking, vehicles tend to turn and take positions oblique to the axis of the track, thus tending to increase the attack of the wheels, particularly those of the braked axles: otherwise all the vehicles take part in the braking whilst on up-gradients the locomotive only is effective through its tractive effort.

The German Federal Railways, who consider that speed is the main factor, have drawn up curves showing the wear per 10 million gross tons as a function of the radius on sharp and gentle down gradients (fig. 5).

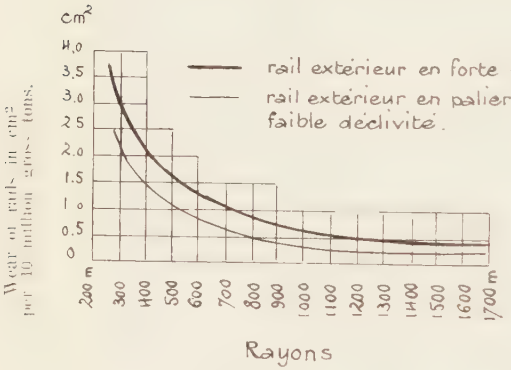


Fig. 5. — Effect of down gradients on rail wear (*German Federal Railways*).

Explanation of French terms:
Rail extérieur en forte pente = outer rail on sharp down gradient. — Rail extérieur en palier ou faible déclivité = outer rail on the level or on slightly falling track. — Rayons = radii.

Influence of rail joints.

Several Administrations consider that the relative position of rail joints (coincident or alternate) and that the method of bedding rails on joint sleepers has no appreciable influence on rail wear. Others consider that by setting joints alternately, wear is not interrupted but with coincident joints these constitute special points about which wear is very small or even non-existent.

The Swiss Federal Railways, however, observe that the presence of alternate joints can, in certain cases, favour rotary oscillation (rolling, torsion, pitching) of vehicles and that joints carried on double sleepers, even on straight track, cause uneven lateral wear of rails, the form of which is shown in figure 6.

Multiplicity of joints in the case of short rails is a cause of irregular wear. Modern methods of laying with long welded rails should have good results, but it does not seem that they have yet been used for curves of small radius.

Influence of the types of sleepers; fastenings and spacing.

These various elements do not appear generally to have any notable influence on lateral wear of rails, subject to suitable initial laying and maintenance. Several Administrations where the sleepers are of uniform type have not been able to make any comparison. However, with track laid on metal sleepers, with which the fastenings effectively maintain the gauge and which offer a high resistance to spreading, the Swiss Federal Railways state that the rails wear in a less irregular manner and probably less severely than with wooden-sleepered track. In fact, the latter is deformed more rapidly in a pseudo-periodic curve and the outer rail wears unequally. In addition, if the fastenings become loose, the widening which results causes increased rail wear as mentioned above.

With regard to spacing of sleepers, this influences lateral wear only so far as it allows the track effectively to oppose deformation of curvature and gauge widening. This influence is barely noticeable within the limits most generally used (1 250 to 1 500 sleepers per km).

Influence of the type and profile of the ballast and surfacing.

a) *Nature of the ballast.* — Sand ballast can, by the projection of abrasive particles

by the wind or by air displaced during the passage of trains, affect lateral wear of the head of the rail on curves (« Soc. Générale des Chemins de fer Economiques, Compagnie Générale des Voies Ferrées d'Intérêt Local », Gafsa, Madagascar and Franco-Ethiopian Railways). On the Matadi-Leopoldville Railway more rapid wear is noticed on rolled gravel than on rammed ballast.

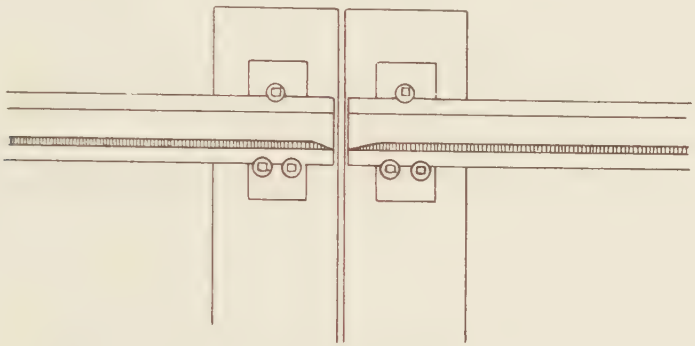


Fig. 6. — Effect of joints on the lateral wear of rails.

b) *Profile of the ballast.* — Insufficient ballast may result in deformation of the lay-out and consequent irregular rail wear. The ballast is sometimes reinforced on curves of various lines, particularly in cases where the authorised speed is greater than that corresponding to the superelevation, but it is difficult to assess the reduced wear which may result.

c) *Surfacing.* — A badly cleaned surface is liable to cause deformation of the lay-out and profile and can have an influence on rail wear.

Influence of climate and atmospheric conditions.

Salt air in coastal districts and chloride sand generally cause oxidation of the web and base. The Tunisian Railways, who coat with tar the web and base of rails, every three or four years in coastal districts, state that the bases wear rapidly, particularly in stations where they come into contact with dirty salt impregnated sand.

The Rhaetian Railway reports the influence of cold and the French Light Railways of the North that of variations of temperature which tend to deform certain curves, causing local wear. Moreover, the latter and the French Light Railways state that lateral rail wear is greater during dry weather than during wet, humidity, and particularly heavy rain, producing on the lateral face a measure of lubrication.

In tunnels, particularly those which are poorly ventilated and at points below cracks in the tunnel roof which allow water to fall, the humidity of the air and the fumes produce a particularly harmful corrosion and the life of rails is considerably reduced. This action, however, is not confined to curved track and is much less effective on the head than on the web.

Wear of rails on switch curves.

Switch curves used for low speed traffic do not show any particular feature in regard to wear of rails.

Thus, on the Tunisian Railways, where speed is reduced to 15 km (9 miles)/h, it is stated that the life of a rail on the larger radius line of a metre gauge turnout, on a 100 m (109 yards) curve without superelevation, is 3 or 4 times greater than on

the outer rail of a 150 m (164 yards) curve on open track. This observation shows the influence of *speed*.

It is otherwise in the case of track connections run over at normal speeds. On these the absence of superelevation and lead-in or their inadequacy, is a cause of particularly heavy lateral wear.

fers only by a few centimetres from that used in the points and is usually quite insufficient for the direction penalised where the wear is much more marked; it is the same in crossings with this condition aggravated by the fact that possibilities of variation of superelevation in it are further reduced, the distance from the point to the

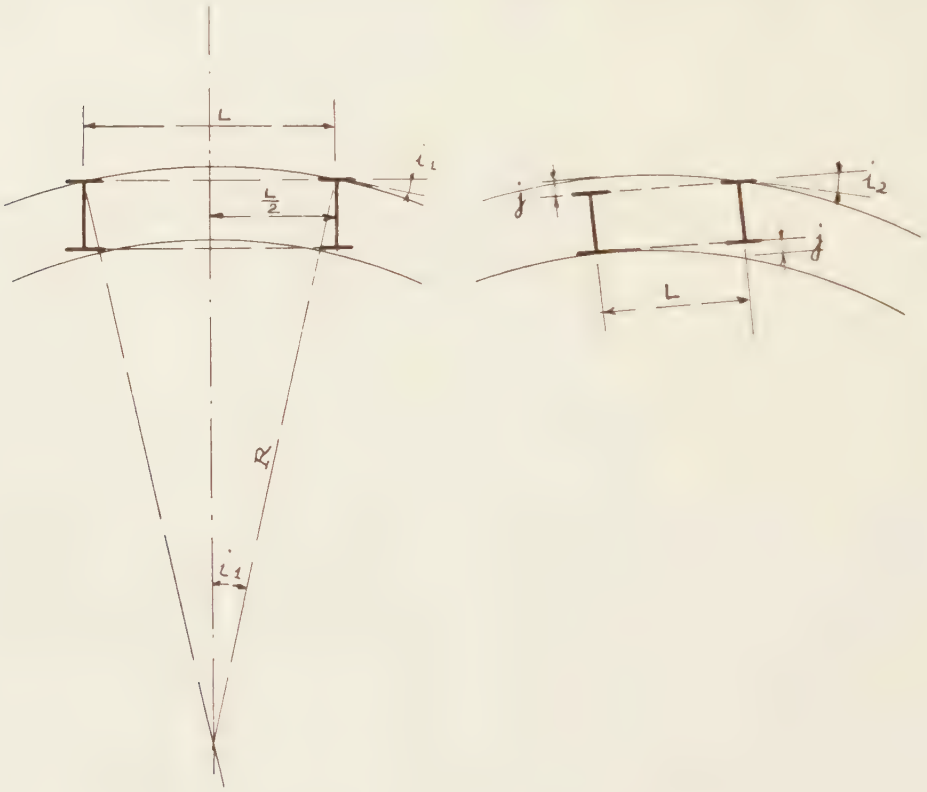


Fig. 7. — Influence of wheelbase. *Angle of thrust.*

The French National Railways point out that in a point's equipment, as increased height could only be obtained by inclining the frame, the superelevation is the same in both directions as far as the tongue of the points and stock rails; beyond that it can vary only by 2 to 3 mm/m (normal superelevation) and consequently the superelevation at the tongue of the points dif-

frame of the crossing being less than that from the point to the tongue.

Rapid wear of switch rails, even with reduced speeds, has led the Swiss Federal Railways to use high-resistance rails, but because of the difficulty of assessing traffic conditions and the influence of the superstructure, it is not possible to establish a precise comparison between wear of these rails and that of rails located on open track.

Predominant factors.

The main influences affecting the track, considered above, may be classified approximately as follows :

a) *Conditions for laying the track :*

— low radius of curvature and relationship between radius and speed of operation;

— inadequacy or excess of superelevation which can often be decided only for a reasonable average speed;

— excessive widening (or sometimes insufficient) in certain curves of low radius;

— insufficient length of parabolic curves;

— steep gradients.

b) *Inherent defects in track maintenance:*

— geometrical irregularities (alignment, level, widening);

— defective behaviour of fastening.

c) *Climate and atmospheric conditions.*

B. — **Influence of certain features of rolling stock.**

Influence of the wheelbase.

The wheelbase which is an essential element in the value of the angle of attack of the flange on the guiding rail has a basic influence on the lateral wear of the latter.

Wheelbase principally comes into play under the following two forms, for determining the maximum angle of thrust or obliqueness of the tyre to the tangent of the rail (fig. 7) :

1) the ratio $i_1 = \frac{L}{2R}$ of the wheelbase to double the radius;

2) the ratio $i_2 = \frac{j}{L}$ of the play of the axle in the track to the wheelbase.

Some values of i_1 and i_2 are given in the following examples :

	Wheelbase L	Obliqueness due : to curvature		to play of the axle in the track		Total obliqueness
		R	$i_1 = \frac{L}{2R}$	j_{max}	$i_2 = \frac{j}{L}$	$i_1 + i_2$
Standard gauge :						
Short bogie	2.50 m	200 m	$6.2 \cdot 10^{-3}$	60	24×10^{-3}	30.2×10^{-3}
4-wheeled vehicles .	9.00 m	200 m	$22.5 \cdot 10^{-3}$	60	6.6×10^{-3}	29.1×10^{-3}
Metre gauge :						
Short bogie . .	2.00 m	100 m	$10 \cdot 10^{-3}$	40	20×10^{-3}	30×10^{-3}
4-wheeled vehicles . .	3.50 m	100 m	$17.5 \cdot 10^{-3}$	40	11.4×10^{-3}	28.9×10^{-3}

It will be seen that i_2 being inversely proportional to L, whilst i_1 is proportional to it, the angle of thrust of a short bogie can be of the same order as a vehicle of long wheelbase. However, it may be noted that, for a given wheelbase and radius, whilst i_1 is fixed, i_2 is variable as a function of the track gauge, the wear of the rails and flanges and the position taken by the axles in the track; the values for i_2 are therefore maxima.

The French National Railways state that :

a) in the case of *bogie steam locomotives*, the displacement of the bogie in relation to the frame, in a curve of given radius increases with the rigid wheelbase of

the locomotive and that the recoil force (whether by springs or gravity) is proportional to this displacement. This means that the angle of thrust of the bogie and the pressure exercised upon the rail are proportionate to the rigid wheelbase of the driving axles; it is therefore the same with the lateral thrust;

b) in the case of *bissel trucks*, wear is generally heavier than with a bogie; in effect, as a bissel truck is often subject to greater recoil (about twice), it exercises greater pressure; furthermore the guiding of the frame is less controlled and the angles of thrust of the various axles are usually larger.

With regard to electric locomotives, the Swiss Federal Railways report that they have no driving bogies with mechanically coupled axles except on articulated locomotives (types Bo 4/6, Bo 6/8 and Co 6/8) on which the angle of thrust of the outer driving axles has been reduced and in this way the wear of the flanges and rails, using a transverse coupling between the two half-frames.

The Belgian National Railways consider that a wheelbase of 4 m (13′ 1 1/2″) appears to be the best from the track point of view, from the following calculation :

« If it is assumed that in all cases the outer wheel of the first axle and the inner wheel of the second or last axle are in lateral contact with their respective rails, there are two « conjugated » wheelbases, which are such that the angle of thrust is always the same. If L′ and L″ represent each of these wheelbases, R the radius and j the total play (play plus slack of gauge) we have the equation :

$$L' \, L'' = 2 \, j \, R.$$

The U.I.C. allows on a straight section a normal play of between 9 and 25 mm (0.35 and 0.98 in.); take an average of 15 mm (0.59 in.). The Belgian National Railways use slacks of 10, 20 and 30 mm (0.39, 0.78 and 1.18 in.) for limits of radii fixed respectively at 400, 250 and 175 m (487, 273 and 191 yards) : we may add to these figures an increase of 5 mm (0.19 in.) due to wear of rail. At the limits indicated, the total play would thus be :

radii above 400 m : 15 + 0 + 5 = 20 mm (0.78 in.);
radii of 400-250 m : 15 + 10 + 5 = 30 mm (1.18 in.);
radii of 250-175 m : 15 + 20 + 5 = 40 mm (1.57 in.);
radii below 175 m : 15 + 30 + 5 = 50 mm (1.96 in.).

The U. I. C. also fixes at 1.50 m (4′ 11 1/16″) the minimum wheelbase (L′) of a bogie; it is assumed that the purpose of this is to limit the angle of thrust. This being so, we find conjugated values of :

radius of 400 m : L″ = 10.67 and 16.00 m (11.66 and 17.49 yards);
radius of 250 m : L″ = 10.00 and 13.33 m (10.93 and 14.57 yards);
radius of 175 m : L″ = 9.33 and 11.67 m (10.20 and 12.75 yards).

This assumes that the rear inner wheel also rubs against the rail with an angle of thrust, but smaller than that of the leading wheel.

The best condition would obtain if L′ = L″; this would give :

$$L'^2 = 2 \, j \, R$$

radius of 400 m : L′ = 4.00 or 4.90 m (4.37 or 5.36 yards), a = 0.0120 or 0.0122;
radius of 250 m : L′ = 3.86 or 4.47 m (4.22 or 4.98 yards), a = 0.0154 or 0.0179;
radius of 175 m : L′ = 3.76 or 4.18 m (4.10 or 4.56 yards), a = 0.0214 or 0.0238;
radius of 150 m : L′ = 3.88 m (4.24 yards) a = 0.0259.

in the case, where the second or last axle whilst in contact would assume a radial position and the angle of thrust would have a value of :

$$a = \frac{L'}{R}.$$

This gives, according to the value given to j, for the limits of radius shown :

On a straight alignment the angle of thrust may reach $\frac{0.020}{L'}$; it would thus vary between 0.00041 and 0.0053. A bogie of 1.50 m authorised by the U.I.C. would have in this case :

$$a = \frac{0.020}{1.50} = 0.0133;$$

on a curve of 150 m :

$$a = \frac{j}{L} + \frac{L'}{2R} = \frac{0.050}{1.50} + \frac{1.50}{2 \times 150} = 0.0383.$$

On the Belgian Railways, curves considered as « sharp » which are most frequently used on main lines, have a radius of 350 m. The best wheelbase for these would be *4.50 m* (4.91 yards). The Landen-Statte line, where the ruling radius is 200 m would demand bogies of 4 m (4.37 yards).

The latter radius is the one used in point lay-outs at the large stations.

In total, a wheelbase of 4 m appears to be the most suitable from the point of view of the track.

Influence of the play which increases the angle of thrust on the guiding rail.

In addition to the effect of the angle of thrust due to play of the guiding axle in the track (considered above), there is that due to lateral play of the journals and axleboxes, and to longitudinal play of the axleboxes in the horns.

a) Lateral play j of the journals and axleboxes may vary from 5 to 20 mm (0.196 to 0.78 in.) approximately according to the stock and its condition of wear; it allows an obliqueness $i'_3 = \frac{j}{L}$ the value of which, for a wheelbase of L = 2.50 m may reach :

$$i'_3 = \frac{20}{2\,500} = 8 \times 10^{-3}.$$

It is desirable that play of the leading axles should be reduced as far as is compatible with good inscription in curves. On the other hand, for intermediate axles lateral play reduces the tearing effect and consequently lateral wear of the rails is reduced.

b) Longitudinal play j'' of the axleboxes in the horns may vary generally from 2 to 8 mm (0.078 to 0.314 in.); this allows an obliqueness of $i_4 = \frac{j''}{d}$, d being the transverse distance between the horns of the same axle or about 1.80 m (1.90 yards) for standard gauge and 1.40 m (1.46 yards) for metre gauge. This gives values of

$$i_4 = \frac{8}{1\,800} = 4.4 \times 10^{-3}$$

for standard gauge

$$\text{and } i_4 = \frac{8}{1\,400} = 5.7 \times 10^{-3}$$

for metre gauge.

This play should have less effect than the preceding type.

In total, the obliqueness due to these types of play, plus those examined above due to curvature and wheelbase, gives in the examples above, the following maximum angles of attack :

for standard gauge (R = 200 m) :

— short bogie (L = 2.50 m) : $a = (30.2 + 8 + 4.4)\ 10^{-3} = 42.6 \times 10^{-3}$;

— long 4-wheeled vehicle (L = 9 m) : $a = (29.1 + 2.2 + 4.4)\ 10^{-3} = 35.7 \times 10^{-3}$;

for metre gauge (R = 100 m) :

— short bogie (L = 2.0 m) : $a = (30 + 10 + 5.5)\ 10^{-3} = 45.7 \times 10^{-3}$;

— 4-wheeled vehicle (L = 3.50 m) : $a = (28.9 + 5.7 + 5.7)\ 10^{-3} = 40.3 \times 10^{-3}$.

The influence of lateral and longitudinal play is therefore far from negligible in the value of the angle of thrust and consequently in the lateral wear of rails. In practice, rolling stock is designed, built and maintained to allow permissible compromises between a reduced angle of thrust and freedom of movement for the vehicle. The « Régie Autonome des Transports Parisiens » consider it advantageous to reduce the play, as follows :

— lateral play { between box and bogie : 3 to 6 mm (instead of 3 to 8 according to wear);
between box and axle : 1 to 2 mm (instead of 2 to 8 according to wear);

— longitudinal play between box and bogie : 3 to 6 mm (instead of 3 to 8 according to wear).

Influence of tyre profile.

Tyre profiles are established for most Administrations on fairly similar lines. The thickness of the flanges, especially, measured at 0.10 m (3 15/16″) below the level of the tread, generally varies between the following limits :

— standard gauge from 33 mm (1.299 in.) (new) to 23 or 22 mm (0.90 or 0.86 in.) (worn);

— metre gauge from 30 mm (1.18 in.) to 18 mm (0.70 in.).

On numerous railways, the flanges on intermediate axles are reduced in thickness to improve inscription on curves. The Swiss Federal and Italian Railways report that they are sometimes dispensed with.

Tyre profiles generally seem to give satisfaction; it is frequently stated that the angle of a worn tyre differs little from that of a new one and that the concave hollowing keeps the same radius (Swiss Federal). The thinner profiles are also satisfactory, subject to them not bearing on the curve, since this would result not only in premature wear of the flanges, but also in their being damaged (French National Railways). However, the Italian Railways consider that on sinuous lines, it would be better to establish more suitable profiles, but that consideration of this question is not sufficiently advanced to allow them to make any proposals.

Influence of wheel diameter.

Most Administrations have not been able to make any effective comparison in this respect, because of the homogeneous nature of their stock, or because of the very different uses of large and small wheels, the dimensions of which vary from 2 000 mm (6′ 6 3/4″) (steam locomotives) to 810 mm (2′ 7 7/8″).

Some consider that large diameter wheels produce more marked lateral rail wear than do smaller wheels. In fact, the distance between the point of contact of the flange and the lateral face of the wheel is a direct function of the wheel diameter; it is the same as a lever to the centrifugal force and consequently to the milling action exercised by the flange.

On the other hand, the Belgian National Railways put forward the advantages of large diameter wheels : reduced resistance to running, increased area of contact with the rail and reduction of wear by abrasion and oscillation; reduction of rail-joint action, new or worn; it is considered that, having regard to the increased weight of electric stock, wheels of 1.0 or 1.12 m (3′ 3 3/8″ or 3′ 8 3/32″) diameter are too small.

The Swiss Federal Railways also observe that the smaller the wheels, the greater the resistances arising from the rail-wheel contact and the more violent the shocks due to rail gaps (joints, points and crossings).

Influence of the effect of oscillation due to the position of the loads.

The distribution of load on the various wheels has an important influence on the stability of vehicles and consequently on the wear of rails. The transfer of load towards the front is in the opinion of the French National Railways bad, because it results in lateral reactions due both to an increased radius of gyration and a reduced distance between the centre of gravity of the machine and the leading axle, which is thus subjected to greater stresses. The influence of such a transfer of load increases with the speed.

The effect of oscillation increasing the lateral shock when running over points or track irregularities, it is important to concentrate as much as possible the motor mass towards the bogie pivot in order to reduce its moment of inertia. The Swiss Federal Railways have stated that motors located outside the bogie wheelbase have caused objectionable shocks to the track; they quote the case of a series of locomotives with rigid frames where the transformer was overhanging the fixed wheelbase and which suffered from fractures of the driving axle next to this overhang transformer, due partly to this factor.

Influence of resistance in bissel trucks and bogies.

When bissel trucks and bogies include recoil arrangements preventing them from taking a cross position on straight track and thus damping any hunting movement, lateral wear of rails increases directly with the recoil effort which tends to hold the guiding axle oblique to the rail.

The Belgian National Railways whose rolling stock will take curves of 200 to 150 m radius fairly easily, quotes the case of a foreign locomotive which caused difficulties on track with 150 m radius curved turnouts because of the limited amount of transverse movement for the bogie pivot, before modification.

Influence of the suspension.

The injurious tendency of the unsuspended motor mass is mentioned later in Part 2.

The Belgian National Railways also recall the following disadvantages which electric stock often offers :

— large unsprung weight;

— considerable stiffness of the suspension to ensure better « holding » of the pantograph;

— rigidity of the bogie (to overcome irregularities of the track).

Miscellaneous influences.

The Belgian National Railways state that propelling of sets, wholly or in part, particularly if they are equipped with centre couplings, must have a bad influence on rail wear.

The French Light Railways of the North and the Portuguese Railways mention the quality of tyre steel. The latter also note the effects of braking on down gradients and poor condition of brake shoes, high speeds and sanding of rails to increase adhesion on up-gradients.

Predominant influences.

The features of rolling stock which have a predominant influence on the wear of rails on curves may be classified as follows :

1) *conditions of inscription of the vehicles :*

— *excessive or inadequate length of rigid wheelbase* of the motive units. Most Railways put this factor first, as it governs the angle of thrust of the flange, on the guiding rail. The Belgian National Railways note that between short and long wheelbases, a good average would be 4 m;

— *stiffness of recoil* devices on bogies and bissels; insufficient guiding of certain bogies;

— *influence of the position of the loads* on the effect of oscillation;

— *abnormal lateral and longitudinal play* allowing excessive angles of thrust;

2) *conditions of suspension :*

— effects of unsuspended masses (particularly motors hung by the nose);

— overstiff suspensions affecting vertical wear particularly;

3) *dimensions of wheels and types of tyre :*

— diameter of wheels (large diameters affecting lateral wear, small diameters affecting vertical wear);

— tyre profiles, improvement of which is desired by some Administrations.

II. — EFFECTS OF THE OPERATION OF LOCOMOTIVES AND RAIL MOTOR COACHES WITH DRIVING BOGIES.

Various Administrations have reported that the introduction of electric or internal combustion engined stock caused a marked increase in lateral wear of rails and a special study of the effect of driving bogies on rail wear in curves would be opportune.

Development of stock with driving bogies.

Experience gained in this matter is very different amongst the Administrations; the development of stock with driving bogies may be summarised as under :

1) certain lines, generally situated in mountainous districts, have been electrified for 30 or 40 years, sometimes since they were built; others for 20 or 30 years, some more recently (Swiss Federal Railways, with 97 % of lines electrified, French, Netherlands, Austrian Federal, German Federal, Rhaetian, Portuguese, Moroccan, Algerian, Belgian, French Northern Light Railways);

2) the introduction of railcars with internal combustion engines, starting about 25 years ago and developed over the past five years.

period 1927-1938 : Moroccan, German Federal, Italian State, Damas-Hamah, Belgian National, French National, French Light Railways, Viet-Nam, Portuguese Railways;

period 1947-1950 : French Local Railways, French West African, Cameroons, Madagascar, Gafsa, Moroccan, Mediterranean-Niger, Luxemburg;

3) the introduction of diesel locomotives, usually with electrical transmission, to replace steam traction, dates from 20 years ago on certain systems (German and Austrian Federal Railways). On those enumerated below, it is more recent (less than five years) : French National Railways, French Light Railways, Algerian, Tunisian, Moroccan, Gafsa, Mediterranean-Niger, French West African, Cameroons, Matadi-Leopoldville, Netherlands, Portuguese Railways.

Principal arrangements for driving bogies.

Table II hereafter gives some essential characteristics of locomotives, motor coaches and railcars with driving bogies, on the various Administrations.

Study of the transmissions between the traction motors and axles and influence on the track of the types of bogie and motor suspension were the subject of Question VI on the agenda of the Rome Congress [1]; we shall therefore restrict ourselves to recalling the following arrangements :

a) number of axles and wheelbase of driving bogies.

Most driving bogies have two axles, both of which are normally driven. Their wheelbase varies from 2.13 m to 4.10 m on standard gauge and from 2 to 2.80 m on metre gauge.

A certain number of electric or diesel-electric locomotives have 3-axle bogies in which generally all three or only two are driven. A special case is that of the railcars with 4-axle bogies on pneumatic tyres of the French National Railways;

b) the maximum weight per axle varies from an exceptional 23 tons (locomotive) to 9 tons (railcars) on standard gauge, and from 13.7 tons on locomotives to 7 tons, exceptionally 3 tons (railcars) on metre gauge;

c) the bogie pivot is usually located in the centre of the wheelbase; it is sometimes away from the centre, particularly when one of the axles is a carrier. With three axle bogies there are sometimes two pivots, on each side of the centre axle, the

[1] *I.R.C. Bulletin :* April 1950 (p. 543) and June 1950 (p. 1145); July 1950 (p. 1529); August 1950 (p. 1633); October 1950 (Special Report by M. HOFFET, p. 2069).

rear pivot transmitting tractive forces and the forward pivot transmitting brake forces. The retraction of the pivot, state the French National Railways, appears beneficial as regards rail wear, as it should reduce the lateral effort of the guiding axle and allow the rear axle to come more quickly into contact with the outer rail;

d) suspension of the body on the bogie. — The weight of the body is transmitted to the frame either through springs, with a swing bolster, or directly through the centre pivot;

e) recoil arrangement. — A large number of driving bogies do not have return arrangements which oppose rotation (diesel-electric locomotives of Moroccan, Cameroons, Portuguese, French Light Railways, railcars of the French National Railways, etc.).

Some have recoil springs (Italian, Austrian, Luxemburg, French West African, Madagascar Railways) or gravity return (Austrian Federal, French National Railways).

On Swiss Federal locomotives, the recoil effort which is intended to hold the body and not to guide the locomotive in the track has no direct influence on the rails.

The resistance of the recoil arrangement is not usually reduced to allow negociation of curves and reduce wear of rails and tyres; controls are considered normally, taking into account the minimum radius of curvature to be negotiated to obtain the best conditions of behaviour on the track, as is the case on the French National Railways;

f) method of motor suspension.

Electric traction motors. — The method of transmitting movement to the axle by having the motor solid with it and suspended by the « nose » from the bogie frame, is used currently. Motors are entirely suspended only on high powered locomotives.

The system of nose suspension, which has the advantage of great simplicity, has the disadvantage of causing lateral shocks on the track, due to the unsuspended mass of the motor (1).

Combustion engines. — On some motor units, the internal combustion engines are placed on the bogies themselves and carried on shock-absorbers. On most units, however, the motors are mounted on the body frame, or are fixed to it by silentblocs. This arrangement is obviously preferable to the former one as regards effect on the track.

Comparisons between the various motor units and vehicles, from the point of view of rail wear.

a) Appreciation of the effects of operating driving-bogie locomotives compared with those of locomotives and vehicles with a rigid wheelbase.

The following eight Administrations consider that driving bogies are particularly heavy on curves :

— the Algerian Railways (particularly on curves of less than 300 m radius, where 3-axle bogies with the outer two driving have a tendency to buck);

— the French West African Railways (3-axle bogies);

— the Cameroons Railways (3-axle bogies where flanges of leading axles wear rapidly, whilst on two-axled bogies, wear is identical on all four wheels;

— Madagascar Railways;

— Matadi-Leopoldville Railway;

— French Light Railways of the North;

— Netherlands Railways;

— Franco-Ethiopian Railway, based on a comparison of rail and tyre wear after 43 years of steam and one year of diesel operation (3-axle bogies).

On the Belgian National Railways, locomotives with driving bogies appear, at least in curves of average radius, to cause

(1) See *Congress Bulletin*, August 1950 (p. 1644 and p. 1645).

TABLE II.

VEHICLES WITH DRIVING BOGIES - STANDARD GAUGE.

L = Locomotives.
A = Railcars and rail motor coaches.
E = Electric.
DE = Diesel electric.
D = Diesel mechanical or hydraulic.

		4 - wheeled bogies.			Six - wheeled bogies			Number of :				Power	Speed km/h
								Bogies		Motors			
		Wheel base a	Distance between pivots b	Maximum load per axle	Wheel base a	Distance between pivots b	Maximum load per axle	driving	carrying	combustion	traction		
		metres	metres	tonnes	metres	metres	tonnes					kWh	
German Federal Railways . . .	L.E				4.60	10.00	20	2	—	—	6	3500	90
	L.E	2.60	14.480	15.5				2	—	—	4	580	80
Austrian Federal Railways . .	L.DE	3.60	15.5	15				1	1	2	2		110
	L.D	4.10	14	15.8				1	1	1			115
Belgian National Railways . . .	L.E											ch	
		2.95	6.0	20.4				2	—		4	2200	100
	L.E	3.60	8.0	20.2				2	–		4	2800	130
	A.E	2.85	14.85	20.5				2			4	1060	120
	A.E (2 articulated)	3.10	15.25	19				2	2	—	4	1060	120
	A.E. (2 articulated)	2.56	14.80	17				4	—		4	1060	140
	A.DE	3.40	13.30	11.7				1	1	1	2	210	90
	A.DE	3.50	18.125	16.9				1	2	1	2	410	140
	A.DE	3.85	17.375	23				2	2	2	4	2x365	150
French National Railways . . .	L.DE				3.50	9.83	18.25	2	—	1	4	760	70
	A.D	2.50	13.60	10				1	1	1		300	80
	A.D	3.00	19.00	10.8				2	—	2		600	75
	A.D	2.80	12.30	11				1	1	1		300	75
Sté. Générale des Ch. de fer Economiques	L.DE	2.13	7.00	17				2	—	2	4	500	65
Régie Autonome des Transports	A.E	2.25	9.30	13.8									

	L.DE				3.50	9.75	21.3	2			4	1000	130	
	A.D	3.50	15.40	11.6				2		2		320	130	
A.D (articulated)		4.00	16.68	13.6				2	2	2		640	120	
Tunisian Railways	L.DE				3.50	9.83	22.2	2		1	4	1500	90	
	A.D	2.50	16.93	9.5				2		1		300	90	
Moroccan Railways	L.E	2.95	6.00	20.5				2			4	1000	60	
	A.E	2.60	11.80	17				2			4	1600	120	
	L.DE				3.50	9.83	20.6	2		1	4	650	96	
Mediterranean-Niger Railway	L.DE				3.50	9.83	23.2	2		1	4	1500	96	
	A.D	4.00	16.68	10.2				2		2		640	90	
Italian Railways	A.D	3.05	16.00	11.5				2		2		170	120	
	A.D	3.00	20.00	15.5				2		1		480	125	
	A.D	2.80	18.50	13.8				2		1		460	125	
Luxemburg Railways		3.50	17.71	10.7				2		2		320	120	
Netherlands Railways	L.E				4.72	8.99	18.5	2			6	3000	125	
	L.E	2.95	6.00	20				2			4	2580	125	
	A.E	3.00	18.35	15.6				2	1	2				
	L.DE	2.13	9.09	14.7				2		2	4	600	60	
	L.DE				4.00	11.58	18	2		1	4	1250	100	
Portuguese Railways	L.DE				3.35	9.14	19	2		2	4	1600	120	
	A.D	2.40	15.40	9.4				2		2	—	274	100	
Swiss Federal Railways	L.E	3.00	7.80	14.5				2			4	2520	125	
	L.E				4.50	9.13	20	2			4	5540	125	
	L.E				4.30	8.70	20	2			6	6000	125	
	L.E				5.20	10.95	20.5	2			4	2040	75	
	L.E	2.50	8.80	17				2			4	1100	75	
	L.DE	2.70	8.30	17				2		1	4	1200	110	
Damas-Hamah Railway	A.D	3.20	12.60	15				2		2	—	210	90	

VEHICLES WITH DRIVING BOGIES - METRE GAUGE.

L = Locomotives.
A = Railcars and rail motor coaches.
E = Electric.
DE = Diesel electric.
D = Diesel mechanical or hydraulic.

		4 - wheeled bogies.			Six - wheeled bogies			Number of :				Power	Speed km h
								Bogies		Motors			
		Wheel base a	Distance between pivots b	Maximum load per axle	Wheel base a	Distance between pivots b	Maximum load per axle	driving	carrying	combustion	traction		
		metres	metres	tonnes	metres	metres	tonnes					ch	
O.T.R.A.C.O. (Belgian Congo)	L.DE				3.22	5.98	15	2	—	1	6	1500	60
	L.DE	2.23	4.70	11.3				2	—	2	4	400	56
French National Railways	A.E	2.34	8.50	7.12				2	—	—	4	290	45
Sté. Générale des Ch. de fer Economiques	A.DE	2.20	10.60	5.3				2	—	1	—	180	70
	A.DE	2.63	12.60	8				2	—	2	—	300	70
Ch. de fer Economiques du Nord	A.E	2.00	10.20	9				2	—	—	4	400	60
Cie. Générale des Voies Ferrées d'Intérêt Local	A.D	2.04	8.32	3				1	1	1	—	150	72
	A.D	2.50	8.92	4				1	1	1	—	65	50
Algerian Railways	A.DE	2.50	9.40	10				2	—	1	4	420	105
Gafsa Railway	L.DE	2.40	17.21	13				2	—	1	4	600	55
	A.D	2.35	20.70	10				2	—	2	—	320	100
Tunisian Railways	L.DE	2.40	7.21	13.7				2	—	1	4	600	90
	A.D	2.80	19.00	11.7				2	—	2	—	600	90
(articulated)	A.D	3.70	10.50	8.25				2	1	2	—	400	90
Cameroons Railway	L.DE				3.41	6.10	11	2	—	1	6	675	50
	L.DE	2.40	7.21	13				2	—	1	4	600	50
	A.D	2.20	16.93	8				1	1	1	—	300	50
French West African Railway	A.D	2.47		11				3	—	1	6	625	60
	A.D	2.20	16.93	10				1	1	1	—	300	70
Franco-Ethiopian Railway	L.DE				2.20	5.56	8.4	2	—	1	4		40
Madagascar Railway	L.DE	1.98	3.82	10.5				3	—	1	6	625	45
	A.D	2.00	7.44	7				2	—	1	—	300	60
Viet-Nam Railway	L.D	2.20	12.6	12.17				2	—	2	—	2x300	
Portuguese Railways	A.D	2.20	10.27	7				2	—	2	—	274	70
Swiss Federal Railways	L.E	2.50	4.70	10.5				3	—	—	4	1215	75
Rhaetian Railway	A.E	2.50	6.20	11.5				2	—	—	4	1600	65
	A.E	2.40	12.76	10.2				2	—	—	4	600	65

more wear than steam locomotives, the latter having less sharp acceleration and generally lower speeds and producing a kind of auto-lubrication of the rail by discharge of steam and water and losses of lubricant.

On the other hand, the following Administrations consider that driving bogies are not particularly aggressive :

— Mediterranean-Niger; Gafsa and Damas-Hamah Railways;

— Moroccan Railways (where Diesel-electric locomotives and railcars inscribe curves very well, even in yards and turnouts of 150 m radius).

Finally the long-wheelbase rail motor coaches of the Italian Railways cause greater wear than any other vehicles, including locomotives with not more than three coupled axles.

The Belgian National, French National and Italian Railways express the opinion that driving bogies are more active in curves than carrying bogies.

b) Appreciation of the effects of driving bogies compared with non-driving bogies.

The French National Railways mention that, on certain railcars, the tyres of 2-axle driving bogies have to be renewed every 6 months, whilst those of 2-axle carrying bogies in the same units have a life of at least 12 months.

The Belgian National Railways state that driving bogies are incontrovertibly more aggressive than those which are not driven, but their loads and often their speeds are higher.

The German Federal Railways, however, consider that this assertion is not proved and that the injuriousness of driving bogie axles is due essentially to their weight.

The Swiss Federal Railways state that a driving is theoretically less aggressive than a carrying bogie in a perfect curve, since a part of the friction is absorbed by the tractive effort or by the brake effort. It can thus be said that on a full curve, *without deformation*, driving bogies are no more aggressive than carrying bogies. On the other hand, on points and crossings, at the entrance to curves, on track irregularities, driving bogies are more damaging in view of their greater mass and inertia which gives rise to shocks, increasing track deformation and rail wear. These facts have been noted at each new electrification.

Finally, all Administrations admit that bogie carriages and wagons are the least aggressive of all vehicles.

c) Classification of vehicles in order of decreasing influence on wear of rails in curves.

In the absence of any systematic measurement, establishment of a classification must be limited to the presumed order of decreasing influence on rail wear. The opinions given on this question are generally based on the relative wear of tyres, considered as directly related to that of rails. They are condensed in the following table (number I corresponds to the vehicles, which appears to cause the heaviest wear) :

Presumed causes of increased rail wear due to driving bogies.

The Administrations, which consider that driving bogies increase wear of rails, attribute their aggressiveness to the following different causes :

1) *weight on axle, particularly unsprung weight,* such as nose-suspended motors, causing particularly noticeable dynamic effects in track irregularities and in turnouts. In addition, the *gyroscopic inertia of the turning masses* (motors and axles) tend to hold the travel of the vehicle to a straight line. Study of this gyroscopic effect however does not appear to have been pursued sufficiently to allow of its evaluation;

2) size of the *angle of thrust* due to short wheelbase, or play in the track, the oscillations which result being the effect of successive shocks. In addition, the *trac-*

Classification of vehicles in order of decreasing influence on wear of rails in curves.

Type of tractive unit and trailers	Administrations listed at beginning of § a)	Belgian National Railways *S.N.C.B.*	Swiss *C.F.F.*	Italian *F.S.*	French *S.N.C.F.*
Locomotives with driving bogies.					
Electric locomotives: without transverse drawgear		2	2	6	
Electric locomotives: with transverse drawgear			3		
Electric motor coaches		1			
Internal combustion locomotives	1				
Internal combustion railcars: long wheelbase					4
Internal combustion railcars: short wheelbase					5
Electric locomotives with rigid wheelbase: without carrying axles			1		
Electric locomotives with rigid wheelbase: with carrying axles			4		
Steam locomotives.					
without bogie or bissel, coupled axles: more than three				1	1
without bogie or bissel, coupled axles: three	2		5	5	
with bogie or bissel, coupled axles: more than three	3			2	
with bogie or bissel, coupled axles: three				4	
Long wheelbase railcars	4			3	
Six wheeled carriages		3			
Wagons and carriages: long wheelbase	5		6	7	2
Wagons and carriages: short and medium wheelbase				8	3
Bogie wagons and carriages	6	4	7	9	

tive effort exerted on the drawbar hook tends to give its greatest angle of thrust to the motive unit and on the contrary to reduce those of the trailing vehicles, the inscription of which, in the curve, is very different from that of the driving bogies;

3) *distance of the motors from the bogie pivot*, affecting the inertia of the whole; some internal combustion engined bogies, whose centre of gravity is farther from the pivot than that of electric motors, cause more flange wear than bogies with electric motors;

4) *a more difficult inscription* of some locomotives depending on the mechanical linkage of the axles to the motor system;

5) *lack of synchronism between the motor torques to the axles*, which may

cause a difference in the rotation of the dicones and in certain cases give rise to oscillation of the bogie, with a hunting motion which will increase as the radius is reduced;

6) finally, the damaging effect of certain 6 wheeled bogies may be attributed to the increased lateral pressure of the flange of the guiding wheel, due to the presence of an intermediate axle.

A combination of several of the above factors appears to contribute to the « floating » of driving bogies in the track, or as it is sometimes called « crab-running », which must increase the irregularities in the wear of rails. The guiding of axles by control devices, such as transverse coupling of bogies, allows the reduction of the angle of thrust of the leading wheels and regulates the running of the bogies.

III. — RESULTS OF INVESTIGATIONS AND REMEDIES ENVISAGED.

A. — Results of investigations.

Nature of investigations carried out.

a) Most Administrations have made observations rather than carried out systematic investigation, the advantages offered to them by these studies depending on the features of their lines. Those who have provided information on this subject are as follows :

— the « Régie Autonome des Transports Parisiens » (R.A.T.P.), which has taken systematic note of lateral wear and actual speed of trains before correcting superelevation each time this was possible in order to reduce lateral wear, and has tried high resistance steel for rails;

— the German, Italian and Rhaetian Railways who have tried extra-hard rails;

— the Swiss Federal Railways, who are particularly interested in research of this type, have undertaken systematic trials on the St. Gothard line [1] over about 25 years, as follows :

1926-1927 : first trials with rails of ordinary quality steel with varying manganese and silicon contents;

1928-1944 : 28 qualities of high resistance rail;

since 1944 : rails of new qualities.

These trials have been pursued on carefully selected sections, firstly on a small scale to provide a preliminary selection between various products and to compare them with laboratory tests; secondly on a large scale to compare them as regards quality, economy and their behaviour in the track. The variation in specific wear per cm^2 in relation to the traffic is noted for the various qualities of rail. Conclusions are made from these with regard to the purchase and use of high-resistance rails.

b) With regard to the study of the contacts between rail and wheel and their effect on rail wear, very little practical work seems to have been done to determine the position of these contacts, apart from the establishement of working drawings. A simple process, mentioned by M. Boutelloup [2] consists of placing on the rail some emery paper and carbon paper; the wheels leave distinct prints on the running surface and on the side of the head. It can thus be said :

« broadly, the tyre is a tool which works on the rail in two ways; by its first contact, it operates as a press, or rather as a roller, effecting in the main a crushing action; by its second contact, it acts as a miller and produces a much more active removal of material. »

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[1] First results of these investigations were given in the *Journées du Rail*, Zurich 1929 and 1932; Budapest 1933; Dusseldorf 1938 and in the paper by M. Genton, Constance, June 1952.

[2] *Congress Bulletin*, October 1952 (see p. 699) : « Geometrical conditions of contact between rail and wheel ».

Continuity, or interruptions, of contact between flanges and exterior rails, which causes abrasion, depend in the main on :

— radius of curve and superelevation;

— characteristics of the locomotive;

— train speeds.

The Belgian National Railways have noted on an electrically operated line with a curve of 2 000 m (2 187 yards) radius, a lateral contact on the left and right alternately, extending each time over about 20 sleepers. The Swiss Federal Railways have noted that the length of the wave in hunting and consequently the wear on the rail, is in the region of 20 to 30 m (22 to 33 yards); it can be obtained by means of recording apparatus located on the vehicles.

Measuring equipment used.

Most Administrations undertake actual measurement of the dimensions of section either, as is most common, by using an adjustable gauge, or by readings from witness marks.

The following apparatus for providing precision profiles are used by various Administrations :

— gauge with orthogonal slides (fig. 8) : Italian State Railways;

— recording device « System Sommer and Runge, Berlin, Model 1920 » with pantograph (fig. 9) : Swiss Federal Railways.

Finally we may report measurements of web deformation by means of a device solid with the base and tracing the lower edge of the head on the outer side of the track.

Relationship between the wear noted and their various causes.

If it is generally admitted that a direct relationship exists between the influences examined earlier, the rules for expressing such wear, based on quantitative experience, have nevertheless not been established.

The Swiss Federal Railways, moreover, state that it is very difficult to dissociate the influence of any one of these factors from the whole, and if it were achieved, it would be necessary to have sufficient results to bring in the law of probability; in addition, such an investigation would be valid only for sections of line where the same types of vehicles were constantly operating, or on closed trial circuits. It is therefore necessary to restrict oneself to qualitative hypotheses.

It can, however, be admitted that specific wear (or reduction of rail section) increases as a function of :

— the curvature of the track: its variation can be between $\frac{K}{R}$ and $\frac{K}{R^2}$ (see Part I above);

— the angle of thrust of the leading axle;

— the axle load (the reaction of the rail

Fig. 8. — Apparatus for measuring rail wear (*Italian State Railways*).

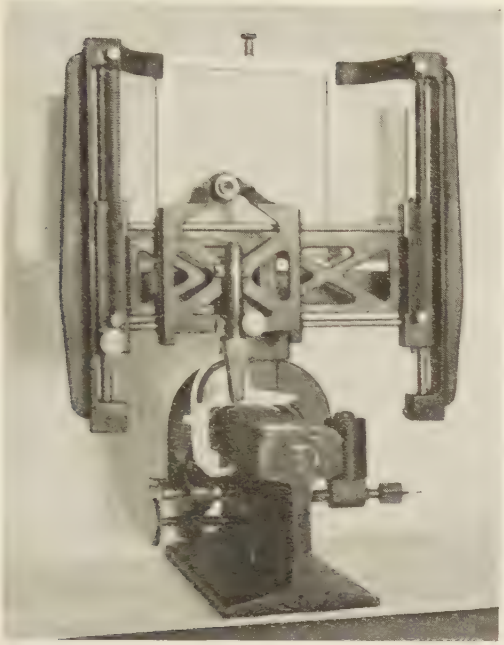


Fig. 9. — Sommer and Runge recorder for measuring rail wear (*Swiss Federal Railways*).

on the flange being proportional to this load and to the coefficient of friction of the wheel on the rail (1);

— the speed of operation (it is recalled that the Austrian Federal Railways consider that lateral wear of rails is noticeable when $\frac{R}{V} = 10$);

— the number of axles working in the curve.

The Swiss Federal Railways have compiled variations in specific wear as functions of traffic tonnage on the basis of systematic measurements of wear carried out over 25 years, which shows :

— reduced variation in the time for specific wear;

— a very small dispersal of results recorded of wear on the same quality of rail;

— intermittent variation of specific wear on the same quality of rail.

It has been recognised that the attack on a new rail is more rapid than that on a chamfered rail, the specific pressure of the flange on a new rail being higher than when the rail has assumed the profile of the wheel flange. The following curves (fig. 10) give several examples of variations as functions of traffic, of specific wear per 10 million gross tons carried by rails of various kind.

Finally, despite the difficulties mentioned, it can be stated that various observations and investigations permit the submission of the formula (1) :

$$A = \frac{S\ f \sin a\ t\ q\ C}{H}$$

in which :

A (cm^3/year) = volume of wear.

S (kg) = pressure of flange against rail.

f = coefficient of friction.

a = angle of attack of leading wheels.

(1) For example according to Dr Uebelacker's theory (*Congress Bulletin* May-June 1922, p. 887) for a locomotive with 4 coupled axles at 1.50 m distances, the maximum reaction obtained when the outer leading wheel alone bears on the rail has a value of :

$R_A = 3.415\ f\ Q$ when the locomotive is running light;

$R_{A'} = 1.984\ f\ Q$ when the locomotive is hauling a load,

(f being the coefficient of friction of the wheel on the rail, the maximum value generally allowed being 0.25 and Q the vertical load on each wheel).

— See also articles by M. Legein, *Congress Bulletin* of September 1929, p. 1547 and September 1938, p. 871.

(1) Article by M. Hoffet. *Revue Technique Suisse*, 1949, No. 49.

t (min/year) = time of contact between flange and rail side, during running of trains.

q (cm³/min) = amount of material displaced during contact of rail and flange.

C = a constant differing according to the vehicle.

H (kg/mm²) = life of steel of parts concerned.

tical wear, particularly if the fastenings are not correctly tightened, which is easily seen, but also on certain railways, on track where the fastenings are in good condition. It may be admitted that the passage of axles causes a slight widening of the track, due to the deformation of the rail. This widening has been proved on the Swiss Federal and French National Railways by comparison between observations of gauge carried out in one case by recording apparatus on a track inspection car on loaded track and

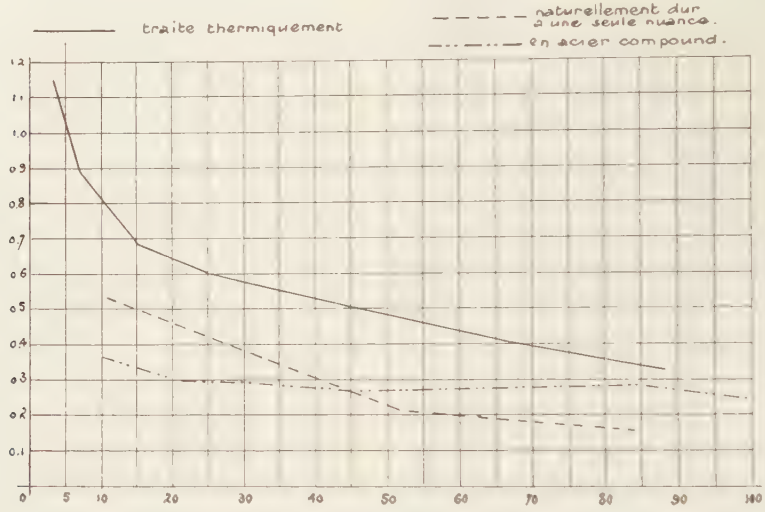


Fig. 10. — Variation of specific wear in relation to traffic.

Explanation of the French terms:
Traité thermiquement = heat treated. — Naturellement dur à une seule nuance = naturally hard, single grade of steel. — En acier compound = compound steel. — Usure spéficique en cm² correspondant à la circulation de 10 millions de t brutes = specific wear in cm² related to traffic of 10 million gross tons.

Investigation of causes of tilt of the running surface of rails.

In connection with this tilting, it is stated :

— it is not very evident in bull-head rails, which can be explained by the resistance to warping created by the chairs (French National Railways and « Soc. Gle des Chemins de fer Economiques »);

— it is manifest on flat-bottomed rails after a certain degree of lateral and vertical wear, particularly if the fastenings are not correctly tightened, which is easily seen, but also on certain railways, on track where the fastenings are in good condition. It may be admitted that the passage of axles causes a slight widening of the track, due to the deformation of the rail. This widening has been proved on the Swiss Federal and French National Railways by comparison between observations of gauge carried out in one case by recording apparatus on a track inspection car on loaded track and in the other case by direct measurement of non-loaded track.

Investigations into modifications of the structure of the metal.

The head of the rail is subjected to a progressive cold surface-hardening. This is more marked as the metal is softer; steel of 70 kg/mm² (44.44 t per sq. inch) tensile is hardened to a depth of several millimetres and may reach about 100 kg/mm² (63 t per sq. inch).

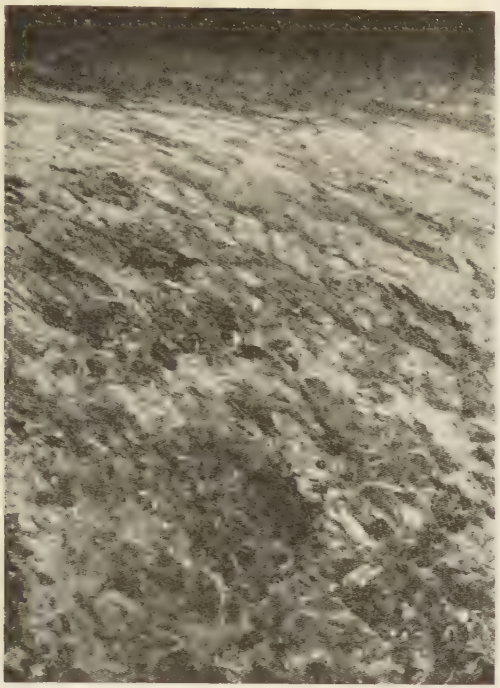


Fig. 11. — Micrograph of top surface of a rail with high wear resistance (*German Federal Railways*).

Magnified	100 times.
Length of service	9 years (Hamburg station).
Composition	C=0.75 Mn=0.73 % Si =0.37 %. P=0.038 % S =0.028 % Cu=0.12 %.
Tensile	93 kg mm² (59 t per sq. inch.).
Perlitic structure.	sorbitic.

The Swiss Federal Railways have recorded on the running surface the formation in service of a layer of metal with a martensitic structure (1); this phenomenon is characteristic on rails affected by undulating wear (see fig. 12).

(1) Tests on the St. Gothard line and Rolling Stock Laboratory investigations at Zurich (Messrs. Ros and Wichser, June 1952).

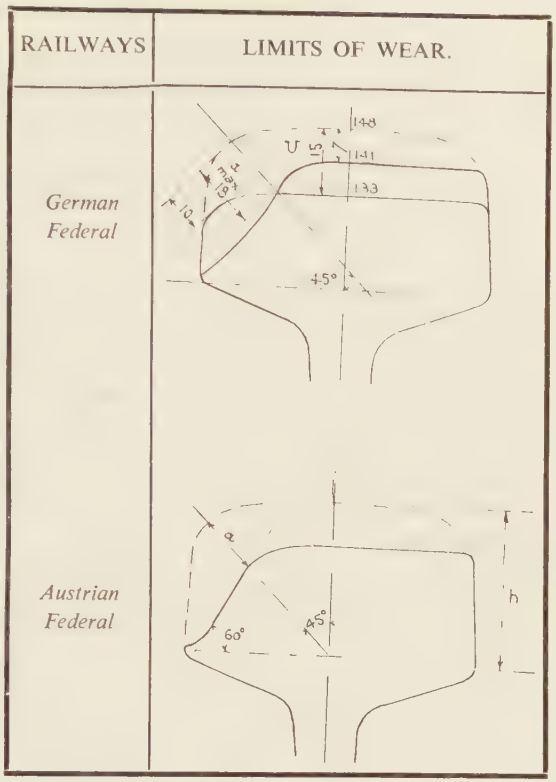


Fig. 12. — Permissible limits of wear.

The German Federal Railways have also noted a hardening of the metal to a very shallow depth (micrograph in fig. 11).

Limit of wear before withdrawal of rails.

Regulations in force. — The following classification may be made of the regulations in force, regarding limits of wear before withdrawal of rails.

1) Lateral wear *a* measured on a straight line at an angle of 45° to the axis of the rail (fig. 12) and vertical wear *v* must not exceed the limits fixed according to the type of rail :

German Federal Railways :

rail $\geqslant$ 48 kg (106 lbs.), a = 18 mm (45/64″), U = 7 mm (9/32″),
$a + U$ = 25 mm (63/64″).

Austrian Federal Railways :

rail $>$ 38 kg (84 lbs.) : $a = 0.52\ h - 4$
rail $<$ 38 kg (84 lbs.) : $a = 0.52\ h - 5$ } chamfer = 60°;

Italian Railways :

width of head of at least 65 mm (2 9/16″) : a = 15;
width of head less than 65 mm : a = 12;

2) The chamfering by lateral wear must not exceed the lower concavity of the head and the upper wear a limit U fixed according to the type of rail; the values of U are the following in the case of simultaneous top and lateral wear :

The Swiss Federal Railways at present allow :

for 50 kg (110 lbs.) rail :
U = 13 mm (33/64″);

for 45 kg (99 lbs.) rail :
U = 11 mm (7/16″);

for 36 kg (79 lbs.) rail :
U = 7 mm (9/32″).

These values are to be modified.

The Rhaetian Railway allows the chamfer slightly to exceed the hollowness of the head.

3) The upper facet of the lateral wear forms with the perpendicular to the running surface an angle of a maximum of 32° on main lines and 34° on other lines (Belgian National Railways).

In addition, on the Netherlands Railways, the height of the head measured on the worn side from the fishing surface, must be not less than 19 mm (3/4″).

4) Lateral wear u is measured horizontally at 15 mm (19/32″) below the running surface. Half its amount is added to the vertical wear U and the total $U + \frac{u}{2}$ must not exceed a limit, varying according to the type of rail, between 8 and 16 mm (5/16″ and 5/8″) (French National, Algerian, French West African and French Light Railways).

5) Lateral wear u measured horizontally at 15 mm or 10 mm according to the Administration, below the running surface must not exceed a limit varying from 10 to 18 mm (25/64″ to 45/64″) according to the type of rail (RATP, French Light Railways of the North, Tunisian, Cameroons, Madagascar, Damas-Hamah Railways).

6) Several Administrations have not fixed a rigid limit and specify that chamfer must not reach the fishing surface or involve risk of shearing the top of the fishplate bolt with a worn tyre.

Bases for establishment of limit of wear.

a) These limits have usually been compiled as a function of the reduction in the strength of the rail, mainly in regard to top wear. For lateral wear, the tendency of the flange to mount the outer rail appears to have been taken into consideration only by those Administrations which specify the angle of chamfer in relation to the rail axis (Belgian National, Austrian Federal Railways).

b) In general, these limits seem to have been fixed empirically. Justification of the limit of lateral wear fixed by the Belgian National Railways was the subject of an

article by M. Jacops (1), which gave the calculation of the coefficient of stability to skidding as $n = \frac{T}{F}$ (relation between the force T which tends to produce skidding along the face of wear and the force of friction F which is opposed to it). For example, with a Belgian Class 10 locomotive (weight on one wheel, 11.2 tons) equilibrium of the opposing forces, $n = 1$, is obtained with a value of 34° 10′ for the angle of inclination of the facet of wear in relation to the rail axis. Numerous measurements have shown that rails of existing track have angles of wear much less than the limits adopted (32° for main lines and 34° for others) which, for the most part, are reached only on turn-outs.

The German Federal Railways are at present undertaking a theoretical investigation. The Austrian Federal Railways limits are based on both theory and practice.

c) It appears that only in exceptional cases can derailment be attributed to climbing of the flange consequent on chamfering of the rail. Certain Administrations consider that the risk is exaggerated; statistical trials by the Austrian Federal Railways on superelevation gradients have shown that relieving the wheel load by 20 to 25 % does not present any danger. Several Administrations state that lateral wear has contributed in certain cases to such rail-climbing. (French Light Railways of the North, Algerian, Madagascar, Viet-Nam, Luxemburg Railways.) The German Federal Railways state that it cannot be considered an essential cause of derailments.

B. — Remedies adopted, tried or under consideration for reducing the wear of rails on curves.

The principal remedies or improvements for reducing this wear, or for increasing the life of rails concern :

1) modification of certain regulations for laying of track (gauge superelevation, position of joints);

2) maintenance procedure; turning of rails or substitution of one line for another;

3) laying of check rails along the inner line;

4) use of rails with a high resistance to wear;

5) lubrication of rails.

1. *Modification of certain regulations for laying of track.*

The majority of Administrations, considering that their regulations have not given rise to any serious difficulties, have maintained them without noticeable alteration. The main modifications reported concern the following points :

a) *reduction of the gauge.* — In order to reduce the play of the axles in the track and consequently the angle of attack, slacking on curves has been reduced by several Railways. As an example the following figures are quoted, dealing only with radii R = 300 m for standard gauge and R = 150 m for metre gauge.

The results observed have been satisfactory but in some cases it is considered to be early to express a definite opinion on the results.

It was stated earlier that the German Federal Railways now use gauge widening only with radii less than 300 m.

On the Italian Railways, reduction of gauge is under consideration with a view to reducing rail wear. On the other hand, the Damas-Hamah and Matadi-Leopoldville Railways have widened the gauge for low radius curves, which appeared insufficient to accept certain vehicles;

b) *modification of the superelevation.* — Several systems have sought to adapt the superelevation to the actual train speeds. The Belgian National Railways, when introducing electric motor coaches, all running at the same speed, replaced the old super elevation formula $D = \frac{820}{R}$ by

(1) *Congress Bulletin,* May 1940 (p. 147).

	Gauge straight	Slack		
		former	present	
S.N.C.B.	1 435 mm	20 mm	10 mm	for R = 300 m (328 yards) standard gauge
Swiss Federal Rys	1 435 mm	20 mm	10 mm	
Austrian Federal Rys	1 435 mm	10 mm	0	
R.A.T.P.	1 435 mm	23 mm	8 mm	
Sté Gle des Ch. de fer Econom.	1 437 mm	23 mm	13 mm	
C. F. Econom. du Nord	1 000 mm	10 mm	0	for R = 150 m (164 yards) metre gauge
Rhaetian Ry.	1 000 mm	12 mm	0	

the theoretical formula $D = 11.85 \frac{V^2}{R}$ where V is the maximum speed (120 km [75 miles]/h), which has had the effect of checking lateral wear of rails, which threatened to become very heavy.

The maximum superelevation has been raised on certain lines. For example, on the RATP, it has been taken from 140 to 160 mm (5 1/2″ to 6 5/16″). On the other hand, superelevation considered to be excessive has been reduced on some lines where slow and heavy traffic was predominant.

The Tunisian Railways consider that it will be beneficial to increase the superelevation to reduce lateral wear of rails on the larger radius line of rails, but on metre gauge, a limit is imposed by the relatively high centre of gravity of the rolling stock, which exaggerates the transfer of loads when running at low speed;

c) *staggering of joints.* — Some Administrations have improved the regularity of curves by substituting opposing joints by staggered joints in curves of low radius.

2. *Turning of rails. — Changing of sides.*

The majority of Administrations currently use one or more of the following procedures for interchanging rails, with the object of placing the chamfering of the head on the exterior of the track :

— reversing, end to end, on the larger radius line : (8 Systems);

— changing to the other side of the track (5 Systems);

— interchanging with rails on neighbouring sections (5 Systems);

— relaying on lines with lighter traffic, or on secondary, yard lines (5 Systems).

Reversing is used if the rails have no permanent bend from the curvature of the track, and if the lengths are not too long to fit in. Changing sides presents the difficulty of the shorter lenghts used on the smaller radius line. The Italian Railways prefer to exchange with lengths from straight track rather than reversing the rail.

On secondary lines of the French National Railways, the first three procedures, which are frequently used, give satisfaction because traffic is light and wear of rails takes a long time to show and only slightly reduces the total strength. On the Swiss Federal Railways, the rails of the outer row are worn on the two faces, generally and especially on very heavily-worked lines such as the St. Gothard. They are reversed only

in rare cases (turntable of sufficient diameter, near a workshop) and more often are relaid on the outer row of a reverse curve.

The procedure for using the two faces of rails gives satisfaction to the Swiss Federal Railways; it requires in return qualities of organisation, economy and vigilance of the staff. On some Railways, however, the useful life of the second face of a rail is very short.

3) *Laying of check rails along the inner line.*

On 8 Railways, the laying of a check rail along the inner line is used, not systematically but in several curves of low radius below the following limits :

— on standard or wide gauge :

300 m (328 yards) : German Federal, Austrian Federal (exceptionally), S.N.C.F., R.A.T.P.;

200 m (219 yards) : Algerian Railways;

180 m (197 yards) : Portuguese Railways;

120 m (131 yards) : Austrian Federal Railways;

80 m (87 yards) : Swiss Federal Railways (in certain special lay-outs, particularly industrial sidings);

— on metre gauge :

50 m (55 yards) : Madagascar Railways.

On the Matadi-Leopoldville Railway, they have sometimes been incorporated in permanent way structures with extension through the full curve.

These check rails have a triple purpose, which differs according to the Railways :

— to defer lateral wear of rails in the outer line by improving the guiding of vehicles;

— for safety, particularly to supplement an inadequate superelevation, in preventing the wheel flange from mounting the outer rail;

— to stiffen the track.

On the German Federal, Austrian Federal and French National Railways, the check rail meets the first two purposes.

On the Algerian and Madagascar Railways, it is designed to prevent derailment and to stiffen the track.

Finally, on the RATP, the check rail is essentially used for safety purposes; fairly well spaced from the rail so as not to affect the guiding of vehicles, it is solely designed to prevent the wheel falling outside the track if it should mount the rail; it also serves to stiffen the track, but has no retarding influence on lateral rail wear in view of the width of the gap.

Apart from this particular case (where it is 100 mm [3 15/16″] for open track and 80 mm [3 5/32″] on turnouts with a gauge of 1 455 mm [4′ 9 5/16″]), the width of the gap is usually related to the gauge of the track.

For example on lines of the French National Railways, it is theoretically equal to the difference between the gauge and keying points of the axle plus the thickness of the flange, or :

$$1 = e - (1.359 + 32) = e - 1.391,$$

or 59 or 64 or 69, according to whether the gauge is 1 450, 1 455 or 1 460 mm. On the German Federal Railways, it is 50 for $R \geqslant 160$ m and 60 for $R < 160$.

On the Portuguese Railways it is :

76 mm (3″) for

R = 180 m; gauge : 1.690;

86 mm (3 25/64″) for

R = 150 m; gauge : 1.690;

R = 100 m; gauge : 1.700.

On the Madagascar Railways it is 75 mm (2 61/64″) for a gauge of 1 025 mm. On the Matadi-Leopoldville Railway it is 92 mm (3 5/8″) for a gauge of 1 067 mm.

The *length of the check rail* corresponds generally to that of the curve, including the transitions; generally it is not extended along the straight section, or for a few metres only.

Several Administrations use special devices for *fixing check rails* :

— specially designed metal chairs which

carry the running rail and the check rail fixed horizontally (German Federal, Austrian Federal Railways, on trial on the Swiss Federal Railways) (fig. 13);

— raised metal bearings used in certain track equipment to avoid canting of the rail and its bearing, also used in track equipment to control the width of the gap (French National Railways);

The other Administrations fix their check rails by means of coach screws, with or without keys, tiebar and bolts.

Whilst the *effect of check rails* on the track is generally satisfactory as regards retarding lateral wear of the rails, the French National Railways, on the other hand, consider that this benefit is eventually off-set by the following disadvantages : the stiffening of the track is prejudicial to good maintenance of the equipment and level; the presence of check rails hinders rectification of level and they themselves constitute a cause of additional rolling stock maintenance; in addition there

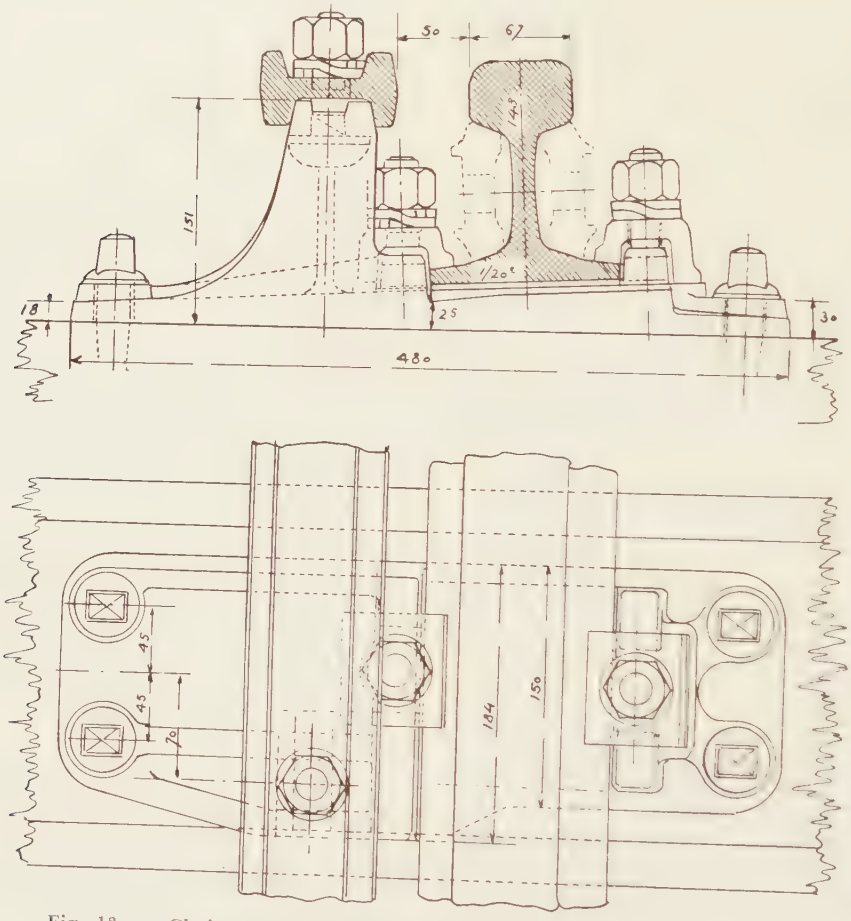


Fig. 13. — Chair with directing check rail (*German Federal Railways*).

is a risk in the event of snow packing the gap.

As regards traction, it is certain — although measurements have not been taken — that checkrails create an additional resistance due to friction between its working surface and the bottom surface of the wheel, which must result, at equal speeds, in higher traction costs. Lubrication of the check rails, used by some railways, considerably reduces this drawback.

4. *Rails with a high resistance to wear* (1).

The use of rails with a high resistance to wear is generally limited, chiefly because of their cost, to curves of small radius, on heavily worked lines. The following 9 Administrations make a widely varying use of them : German Federal, Austrian Federal, Belgian, Luxemburg, Netherlands, Italian, Swiss Federal, Rhaetian Railways and Régie Autonome des Transports Parisiens (R.A.T.P.).

These rails may be divided into 3 categories :

— *naturally hard rails* of a single type of steel having the same composition throughout the section:

— *compound steel rails,* in which the wearing surface of the head only is of naturally hard steel, whilst the web, base and remainder of the head are of ordinary steel;

— *heat treated rails,* in which the head alone is tempered after rolling.

1) *Rails naturally hard, of a single type of steel.*

The resistance to wear of these rails is increased by modifying their chemical composition. Amongst the special steels most used are those with a high manganese content; mention may also be made of nickel and nickel-chrome steels.

Manganese steel. — From 1907 to 1920 the Paris Metro (RATP) used 244 tons of 52 kg (115 lbs) rails having the following mechanical characteristics :

tensile strength : 100 kg/mm² (63.49 t per sq. in.);

elongation : 60 %;

elastic limit : 45 kg/mm² (28.57 t per sq. in.).

During more than 12 years service, these rails have behaved perfectly; subsequently many of them have had to be withdrawn because of heavy wear, breakage or various defects. There remain about 40 % of them, the life of which varies from 33 to 46 years, the average wear being :

Larger radius rail :	vertical	wear 4 to 8 mm;
	lateral	wear 4 to 11 mm;
Smaller radius rail :	vertical	wear 8 to 13 mm.

These rails with a very high manganese content, laid more than 30 years ago, have not shown particular resistance to wear. Apart from their very high cost, they have the following disadvantages :

— difficulty of obtaining lengths of more than 9 m (20′ 6 3/8″);

— practically impossible to cut and drill on site;

— sensitive to heating produced by accidental skidding of wheels on up-gradients, which results in formation of depressions in the running surface.

Since 1928 and 1931, the German Rail-

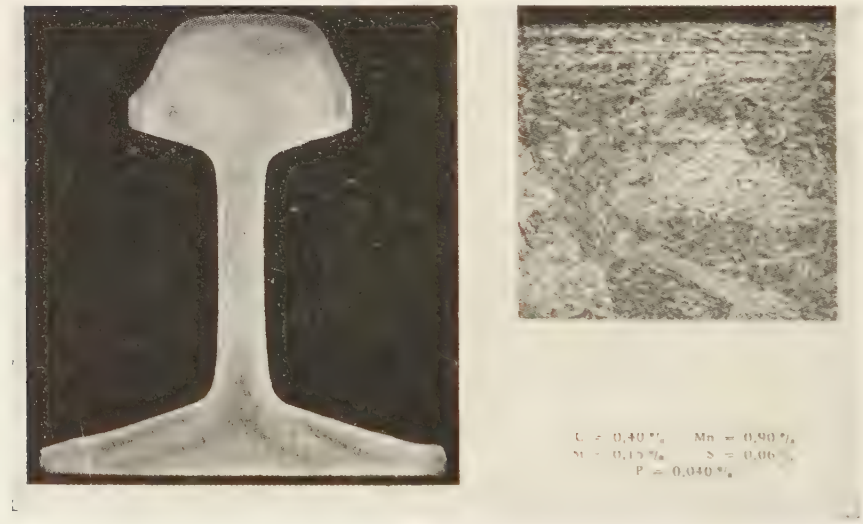
(1) It is recalled that resistance to traction of steel currently used for rails and tyres generally have values of :

— rails : at least 70 kg/mm² (44.44. t per sq. in.) (65 kg [41.27 t per sq. in.] on some railways);

— tyres : at least 75 kg/mm² (47.62 t per sq. in.).

(R.A.T.P. : at least 70 kg; German Federal : 80 to 92 [50.79 to 58.41 t per sq. in.] for locomotives and 60 to 72 [38.09 to 45.71 t per sq. in.] for wagons; Swiss Federal have on trial, tyres of 80 to 92 kg for locomotives and in service 7 % of the axles of carriages and wagons are fitted with monoblock wheels with a tread and flange having a resistance of 108-110 kg/mm² [68.57 to 69.84 t per sq. in.].)

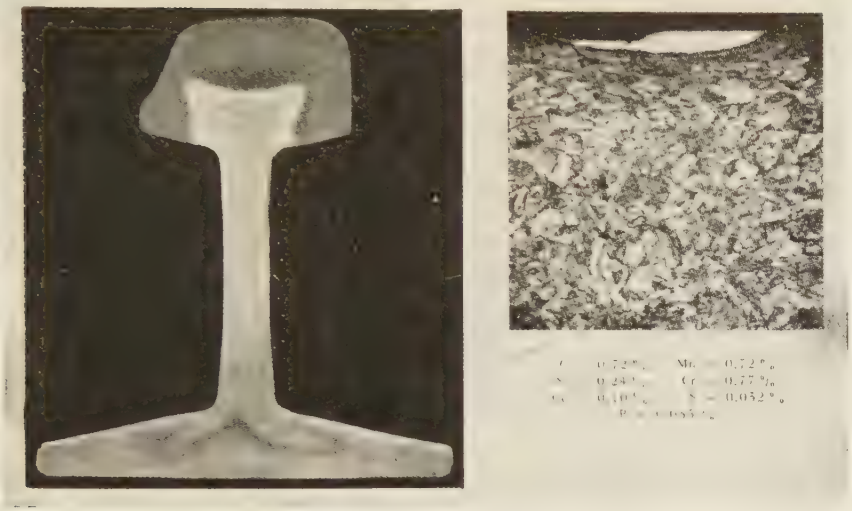
a) Naturally hard, single grade of steel.



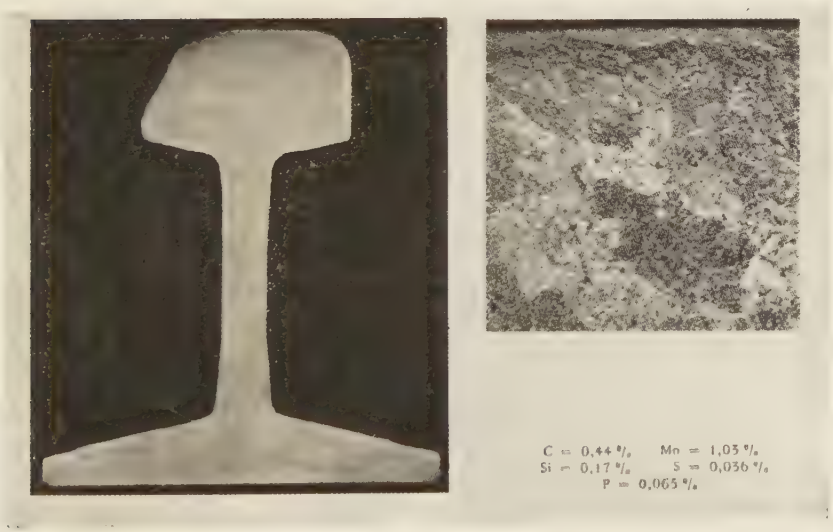
c) Heat treated rail.

Fig. 14. —Rails of steel with a high resistan

(*Swiss F*



b) Compound rail.



d) Heat treated rail.

withdrawn in 1944 from the St. Gothard line

ays).

ways have laid rails of manganese steel of the following approximate compositions :

— content, high in C (0.7 to 0.87 %); moderate in Mn (0.6 to 0.77 %).

— content, lower in C (0.3 to 0.65 %); higher in Mn (1.5 to 1.6 % and up to 2 %).

Subsequently, only the latter with a sorbitic-perlitic structure (resistance to fracture of 90 to 105 kg/mm² [57.14 to 66.66 t per sq. in.]) have been used by the German Federal Railways.

The Austrian Federal Railways have used rails of this type in curves of radius equal to or less than 300 m, also the Italian and Rhaetian Railways (where the latter have a curve development representing 46 % of the track length). The Netherlands Railways use on a restricted scale rails of Siemens-Martin steel (minimum tensile 90 kg/mm² [57.14 t per sq. in.], minimum elongation 12 %, average composition C = 0.58 %, Mn = 1.45 %).

The Swiss Federal Railways have for 25 years been using naturally hard rails with a high manganese content, particularly on the St. Gothard line which, comprising curves of low radius (280 m) almost without break and heavy gradients (up to 28 mm/m) over a large part of its length and carrying a very heavy traffic (about 5 million gross tons per year) constitutes a very advantageous field of experience (fig. 14*a*). The main characteristics of these rails vary within the following limits :

Quality	Date of laying	Loads in million gross tons up to 6/1952	Wear in cm² per 10 million gross tons	Chemical analysis C.	Mn	Si	Tensile strength kg mm²
S-M. high manganese content	1-1935	86	0.158	0.63-65	1.53-1.54	0.30-32	90-102
—— do ——	8-1950	10		0.56-66	1.36-1.68	0.27-40	93- 99
Electric Mn	1948	15	—	0.47-60	1.71-2.04	0.11-24	86-121
—— do ——	8-1950	10	—	0.50-61	1.75-2.06	0.08-30	85-95

As an example, comparison between rails of ordinary quality and rails of electric manganese steel, laid in 1928 and 1931 respectively on the section from Lavorgo to Giornico, where wear is particularly heavy, provides the following results :

Quality of steel	Resistance to fracture	Life after turning	Total wear	Specific total wear per 10 million gross tons operated
Ordinary	60—70 kg/mm²	2 1/2 years	6.9 cm²	4.3 cm²
Electric Mn	90—95 kg/mm²	12 1/2 years	5.2 cm²	0.65 cm²

Thus the life of the latter in this case has been five times greater than that of ordinary quality rails.

— *Nickel steel.* — In 1912, the Paris Metro carried out a first test of nickel steel rails (0.50 % C; 0.58 % Mn and 2.7 % Ni):

tensile : 77 kg/mm² (48.89 t per sq. in.);
elongation : 12 %;
elastic limit : 38 kg/mm² (24.13 t per sq. in.).

In 1932, a fresh trial was made in curves of 75 to 100 m radius with rails of electric-hearth nickel steel, containing 2.3 % Ni (90.5 kg/mm² [57.45 t per sq. in.] tensile). The recooling of these rails after rolling was too rapid and the metal became air-tempered, which rendered it brittle and gave rise to numerous defects and fractures.

— *Nickel-chrome steel.* — In 1936, the Paris Metro laid in curves of 70 to 105 m radius, 230 tons of nickel chrome steel rails, having the following characteristics : 0.35 % C; 0.74 % Mn; 1.61 % Ni; 0.77 % Cr; tensile 98 kg/mm² (62.22 t per sq. in.); elongation 14 %.

Fig. 15. — Macrograph of composite rail
(*Italian State Railways*).

Laid in curves of 75 to 100 m radius, their life was 24 years, whilst that of ordinary quality rails — tensile not below 75 kg/mm² (47.62 t per sq. in.) — in such curves is about 10 years.

Of these rails 96 % have been in service more than 16 years; their average vertical and lateral wear is 4 to 6 mm (5/32″ to 1/4″). Their price was double that of ordinary rails; it may be hoped that their life will be at least double. Taking into account the saving in labour from deferred relaying, their use seems clearly advantageous and the test is to be extended.

2) *Rails of mixed steels* (bi-metal compound steel (Verbundschiene »).

These rails comprise, so far as the nature of the steel is concerned, two separate parts :

— that subject to wear (top and side faces of the head) of manganese and chrome steel : C = 0.7 to 0.8 %; Mn = 0.7 to 0.85 %; Cr = 0.77 to 0.8 %; tensile 110 to 135 kg/mm² (69,84 to 85,71 t per sq. in.);

— the remainder of the head, web and base are of semi-hard carbon steel.

The German Federal, Swiss Federal (on the St. Gothard line since 1931, for trial — fig. 14*b*) and Italian (fig. 15) Railways use these rails, the first in tracks of important yards and the others on curves of low radius. Their cost is very high, but their life is 3 to 4 1/2 times that of rails of ordinary quality.

3) *Heat-treated rails.* — The head of the rails so treated only receives a tempering by more or less rapid re-cooling, after their removal from the rolls. According to the method used, distinction may be made between sorbitic and martensitic rails.

Sorbitic rails were laid from 1928 to 1930 by the Paris North-South Railway (quantity 200 tons, resistance to fracture 80 to 88 kg/mm² [50.79 to 55.87 t per sq. in.], elongation 9 to 13 %); after 23 to 25 years service their average vertical wear is 4 to 6 mm and lateral wear 8 to 10 mm (5/16″ to 3/8″) in curves of 100 to 150 m radius. Because of the good results with these rails, the R.A.T.P. equipped a suburban line in 1938 with rails of this type and these have been satisfactory for 15 years.

Rails of sorbitic structure laid by the Swiss Federal Railways on several sections of the St. Gothard line have the following characteristics :

Date		Load in million gross tons up to 6-1952	Wear in cm² per 10 million gross tons	Chemical analysis			Tensile strength of base kg/mm²	Brinell hardness
laid	reversed			C	Mn	Si		
7 -1931	3-48	100	0.322	0.41-49	0.87-1.06	0.10-14	75-78	295-350
11-1944		35	0.455	0.40-50	0.92-1.06	0.07	—	300-375

The German Railways, during the last war, laid for trial sorbitic rails of 105 to 120 kg tensile, the life of which is 1.6 to 2 times greater than that of current quality rails.

Martensitic rails. — Since 1928, rails used by the German Federal Railways have been tempered by sudden immersion, from a temperature of 820° reduced to about 200° in a water tank which produces a martensitic structure on the tread and cheeks of the head. The hardness obtained is very high (tensile 120 to 160 kg/mm² [76.19 to 101.58 t per sq. in.]), the rails are very resistant to wear, and their life is 3 to 4 1/2 times that of ordinary rails.

The Swiss Federal Railways, about the same time, laid some rails having the following characteristics (fig. 14*c* and *d*) :

Date		Load in million gross tons up to 6-1952	Wear in cm² per 10 million gross tons	Chemical analysis			Tensile strength of base kg/mm²	Brinell hardness of treated part
laid	reversed			C	Mn	Si		
2-1934	7-45	88	0.290	0.44-50	0.84-1.07	0.10-15	75-78	300-395
12-1937	7-45	73	0.243	0.35-36	0.88-0.96	0.71-73	71	375-435
1948	—	15	—	0.38-44	0.90-0.98	0.07	82-85	255-515

The Netherlands Railways have put down some rails treated on the Sandberg principle, with a composition about the same as the above, the tensile of which is 80 to 95 kg/mm² (50.79 to 60.31 t. per sq. in.) with elongation of 8-10 %.

In 1950, the German Federal Railways put on trial some rails hardened by high frequency induction. The steel of 70 kg mm² (44.44 t per sq. in.) gradually reaches 130-140 kg/mm² (82.54 to 88.89 t per sq. in.) in the zone of the edges of the tread and the checks. These trials are too recent to allow an opinion to be expressed but the process is economic and seems to be very promising for providing high resistance to wear.

In 1950, the R.A.T.P. laid, in curves of 220 to 250 m radius (Paris suburban lines) 40 tons of rails of a similar constitution, the process used being characterised by the tempering of the two sides of the head (martensite), whilst the middle part of the tread, protected during immersion has a transitional structure (martensite, troostite, sorbite). The superficial hardness obtained corresponds to tensile of 135 to 145 kg/mm² (85.71 to 92.06 t per sq. in.) for the sides of the head (Brinell hardness over 375) and 95 to 105 kg/mm² (60.31 to 66.66 t per sq. in.) for the centres of the tread.

After 17 months service, five lengths showed longitudinal cracks in the transition region at various parts of the head central portion. No other serious defect has been noticed and undulating wear is scarcely visible after two years, although this has caused the replacement of sorbitic rails at the end of one year service. However, the use of these rails cannot be extended to curves of 75 to 100 m radius as their curvature usually results in longitudinal cracks.

The treated rails of the Italian Railways have an average composition : C = 0.60 %, Mn = 1.4 %, tensile 90 kg/mm² (57.14 t per sq. in.) after rolling increased to about 110 kg/mm² (69.84 t per sq. in.) after head treatment (fig. 16).

The Luxemburg Railways have recently used some rails (C = 0.5 %; Mn = 1.1 %) heat treated in the following manner :

— treatment of the whole tread (in curves of 1 000 m radius and below);

— treatment of the edges (in curves of more than 1 000 m radius).

The Belgian National Railways use only treatment of the edges by cooling with compressed air, although former experience has not been satisfactory.

Rails of the above types have, in general, given satisfaction as regards resistance to wear. The Italian Railways have authorised the use of compound rails and of heat-treated rails (fig. 17) considering that they may tend to eliminate the propagation of cracks in the running surface. On the other

hand, several defects have sometimes been noticed by the various Administrations, particularly on the running surface (mainly scaling and undulatory wear) and a certain brittleness (breakage or cracking). Moreover increased resistance to wear beyond a certain value loses its advantage if the life of rails is terminated by such defects. To reduce these as much as possible, it appears that there should principally be :

— for naturally hard rails, an investigation into the optimum manganese content, in the absence of other definite criterion of resistance to wear (it appears that the content should be about 1.3 to 1.5 %) and into the best conditions for cooling after rolling;

— for heat-treated rails, to investigate the steels used for rails, before proceeding with heat treatment, to select those qualities which offer the best results.

Use in track equipment of high resistance rails.

Five Administrations use rails with a high resistance to wear in track equipment (German Federal, Algerian, Luxemburg, Swiss Federal and Portuguese Railways), apart from the cast steel frogs which provide a notable reduction of maintenance expenses. The German Federal Railways use rails with a tensile of 90 kg/mm² (57.14 t per sq. in) in curves of 500 m radius. The Luxemburg Railways use heat treated rails for points and crossings as well as for open track. The Swiss Federal Railways have since 1934 used high resistance rails in the manufacture of track equipment, for stockrails, blades, wing rails, as well as junction rails, the use of heat treated rails being forbidden for machined parts. High resistance rails are now no longer used by them except for the outer line of the turnout, connecting the point and the crossing; all other uses have had to be given up for reasons of safety, in view of the high rate of breakage or defects recorded on point equipment incorporating these rails. They suggest that systematic investigation should be undertaken to determine the possibility of heat-treating naturally hard rails of a single grade of steel, for use in the construction of track equipment.

Lubrication of rails.

Sixteen Administrations out of the 26, who replied, use various methods of lubricating the interior face of rails on the larger radius. Lubrication is done either directly on the rail or on the wheel flanges. The processes and equipment can be classified as follows :

1) manual lubrication of rails and wheel flanges;

2) manually-operated equipment fixed to a trolley;

3) lubricators fixed to the rail at the ends of certain curves and operated by the wheels;

4) equipment fitted on the rolling stock, lubricating either the rails directly, or the wheel flanges.

Description of the processes and equipment.

1. *Manual lubrication.*

a) *Manual lubrication* of rails by a grease brush is done by several Railways, either in exceptional cases on curves of low radius or in certain areas (German Federal, Algerian Railways, « Soc. Gle des C. F. Economiques », French Northern Light Railways, Cameroons and Luxemburg Rys.), or when an automatic lubricator is insufficient (R.A.T.P.), or more systematically (Cameroons, Madagascar, Viet-Nam, Rhaetian Railways).

The German Federal state that on the sections affected, lubrication with graphited oil is carried out once per week by a man carrying an oil receptacle on his back and using a long-handled brush or felt roller.

The Madagascar Railway uses « Guerneguez » and « Biberon » equipment with graphited oil and grease respectively.

b) *Hand lubrication of wheel flanges* is done by the Swiss Federal Railways when locomotives leave the shed; a mixture of black axlebox oil and powdered graphite, is brushed on the surface of the flanges of the wheels.

2. *Manually operated equipment fixed to a trolley.*

A device of this kind, used by the German Federal Railways for several years, is now used only on a very short section during very dry weather. The Swiss Federal Railways state that they do not use this method, which has the disadvantage of immobilising a vehicle on a fairly short section.

3. *Lubricators fixed to the rail and operated by the wheels.*

Fixed lubricators, mounted on the outer line of rails at the ends of the curves to be lubricated automatically emit a small quantity of oil or grease taken by the flange of each wheel during its passage. The equipments used are « P & M » (London), « Aladdin » (London) and « Racoor 4 000 » (New York).

a) *The « P & M » equipment* is used by the French National, Belgian, Algerian, Italian, Netherlands and Swiss Federal Railways; other Administrations are considering its adoption (fig. 18).

It comprises essentially a grease tank and two pumps fixed outside the track and a lubricator plate fixed to the inside. Its operation is as follows : the lubricant in the tank is forced by a helical spring to the cylinders of the two pumps, the pistons of which are held in their top position so that the piston head is 6 mm higher than the head of the rail. By the action of the wheels on the piston heads the lubricant is forced from the pumps through orifices in the two bolts which secure the equipment to the web of the rail into a space between the bottom of the head and the top of the pad on the lubricator plate and then to the top grooves of the latter. The wheel flanges in contact with this plate pick up the grease and carry it along the inner head of the curve.

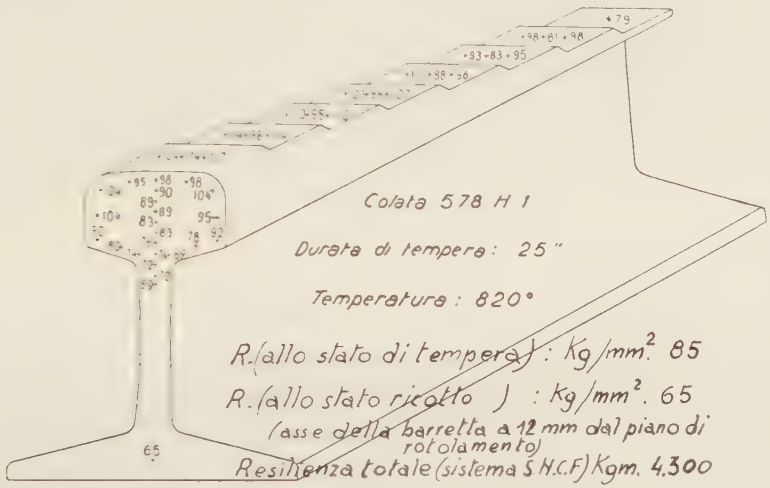
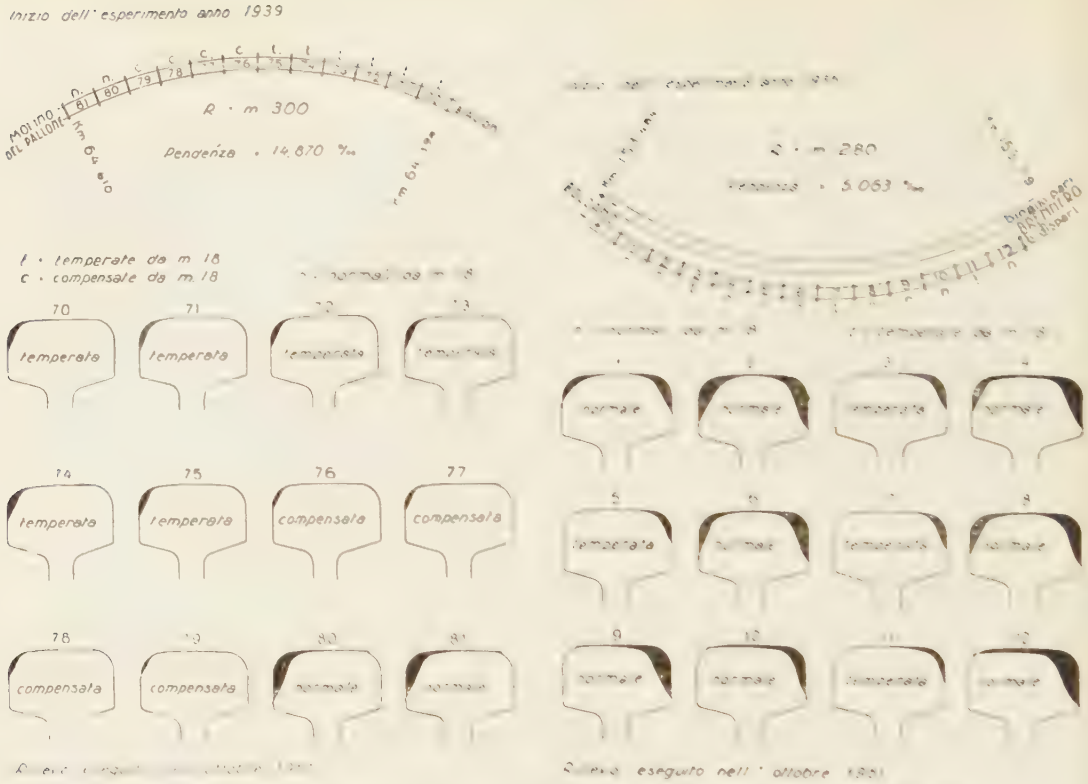

Colata 578 H 1
Durata di tempera: 25"
Temperatura: 820°
R. (allo stato di tempera) : Kg/mm² 85
R. (allo stato ricotto) : Kg/mm². 65
(asse della barretta a 12 mm dal piano di rotolamento)
Resilienza totale (sistema S.M.C.F) Kgm. 4,300

Fig. 16. — Tensile strengths of heat treated rail (*Italian State Railways*).

b) *The « Aladdin » equipment* (Italian State Railways experimentally, and Swiss Federal Rys.) is fixed to the rail by two



Lateral wear of heat-treated normal rails and composite rails (*Italian State Railways*)

Fig. 17 — Lateral wear of a normal rail and a composite rail.
(Life : 10 years in a curve of 300 m [328 yards] radius.)

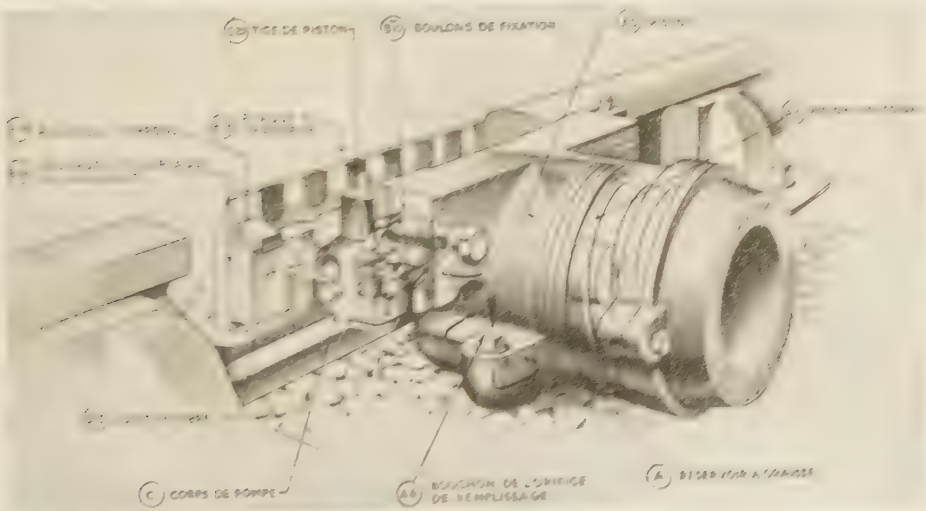


Fig. 18. — « P & M » lubricator

Tige de piston = piston rod. — [illegible]
Fourrure de la plaque de graissage [illegible]
plate. — Joint en fibre = fibre [illegible]
pump. — Bouchon de l'orifice de [illegible]
tank. — Ressort hélicoïdal = helical [illegible]

straps which avoids drilling the rail. The tank holds 3.5 kg (7.7 lbs.) of grease, the distributor has a length of about 0.50 m (1′ 7 11/16″) as with the previous apparatus. Grease is emitted under the effect of vibration of the rail during the passage of vehicles.

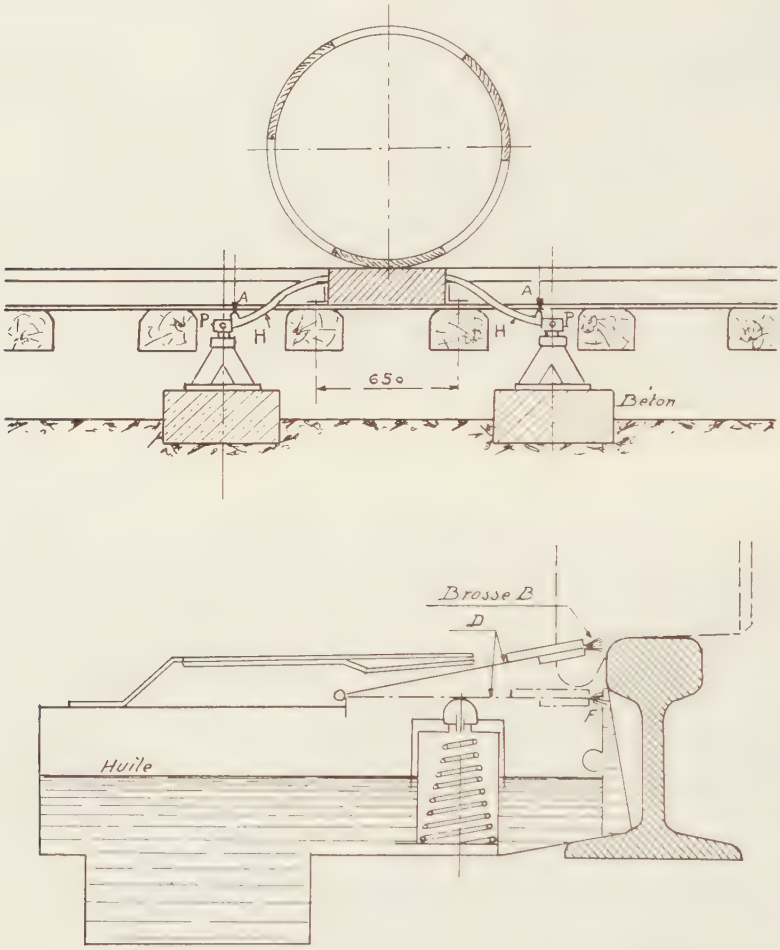


Fig. 19. — « *Paehler* » lubricator (*German Federal Railways*).
Béton = concrete. — Brosse = brush. — Huile = oil.

c) *The « Paehler » system* (German Federal Railways) located entirely within the track, against the rail, is, in essence (fig. 19) a tank and oil pump, two levers operating on the moveable lid of the tank, which ends in a brush. The flexing of the rail during the passage of an axle works on a lever which lowers the lid and brush; by this movement the oil is forced through an orifice to soak the brush, which lubricates the head over a length of 50 mm (2″).

d) *The « Racoor 4000 » equipment*, used by the Italian Railways — on trial — com-

prises a distributor plate about 2.70 m (8 ft. 18 1/4 in.) long and a box containing the mechanism, the whole being fixed to the rail by several bolts through the web; the first on the interior, the rail head having been machined over the corresponding spring and on the return stroke actuates the mechanism in the box which by the rotation of a rod and the movement of sprockets, pumps and piping, forces the grease from the tank to the emission points on the distributor.

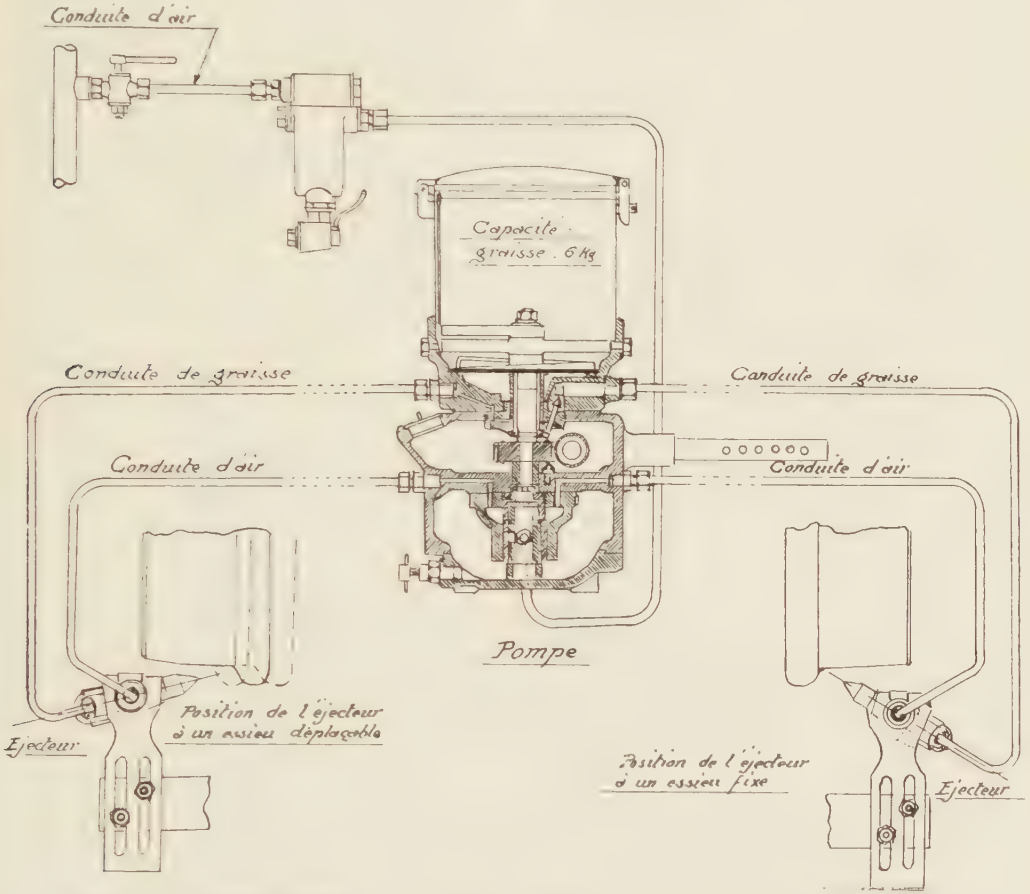


Fig. 20. — Flange lubricator « *De Limon, Fluhme & Cy* » (*German Federal Railways*).

Conduite d'air = air pipe. — Conduite de graisse = grease pipe. — Capacité graisse : 6 kg = capacity grease = 13 lbs. — Ejecteur = ejector. — Position de l'éjecteur à un essieu déplaçable = position of ejector on movable axle. — Pompe = pump. — Position de l'éjecteur à un essieu fixe = position of ejector on fixed axle.

length, the second outside the rail; in addition a grease tank of high capacity (over 100 kg [220 lbs.]) is half-buried outside the track. The piston, depressed by the passage of each wheel, is lifted again by a strong

4. *Equipment fitted to motive units or rolling stock.*

A. *Flange lubricators.* — Six Administrations use flange lubricators : German Federal, Austrian Federal, French West Afri-

can, Madagascar, Italian, Swiss Federal and Rhaetian Railways. The equipments used are as follows :

a) *the Bertschmann* system (French West African and Rhaetian Railways) of two telescopic tubes and a pad supplied with oil from the movement of the locomotive; the pad is replaced every 150 km (93 miles);

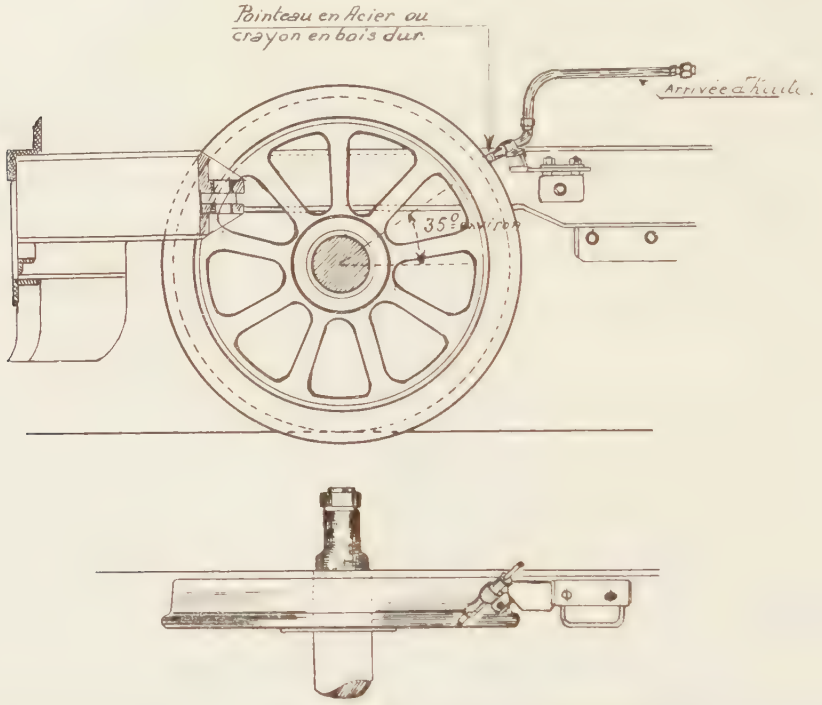


Fig. 21*a*. — Flange lubricator (*Swiss Federal Railways*).

Pointeau en acier ou crayon en bois dur = feeler of steel or hardwood. — Arrivée d'huile = oiling point. — Environ 35° C = about 95° F.

b) *the Buclon* system (Madagascar Railways);

c) air or steam ejectors (Madagascar Railways) mounted on the locomotive frame;

d) « *Limon, Fluhme & Co.* » *equipment* (German Federal Railways) used particularly on up-gradients (fig. 20) comprising essentially a grease pump connected to a compressed air supply, from which two pipes are taken for air and grease respectively to an ejector located near of the wheel flanges concerned.

e) *feelers* are used by the Swiss Federal Railways (fig. 21*a* and 21*b*), in particular those of the « Friedmann » type of case-hardened and tempered steel, fixed to run on the flange at an angle of about 30° above the horizontal; oil is led to the feeler during the movement of the vehicle by a pump which is in operation in one direction of travel. The steel feeler can be replaced by a hardwood pencil. A very simple similar device works without a pump, the oil being fed by gravity only.

A feeler of the same type is used by the Italian Railways. On the Matadi-Leopoldville Railway the flange is lubricated by a

graphite rod held in a metal sleeve and held on the flange by spring pressure.

B. *Rail lubricators carried on locomotives or rolling stock.*

These devices lubricate the inner face of the rail.

a) The principle of *automatic lubrication of curved track,* used by R.A.T.P., is as follows (fig. 22) : the equipment is fitted to the leading bogie of a trailing vehicle; an oil emulsion is projected into the inner face of the head of the rail in curves of less than 250 m radius by means of a nozzle on the bogie. The lubricant is stored in a tank under pressure from the brake pipe and is emulsified on leaving the tank by a vaporiser which feeds two pipes; each of these is controlled by an electro-valve, connected to a projector nozzle above each line of rail. Energising of the electrovalve coil is done by two contacts in series; one is made by an oil relay controlled by the axle when the vehicle is in motion, the other by a device controlled by the angular displacement of the bogie relative to the body, working only when the displacement reaches a value greater than that obtained with a 250 m radius curve.

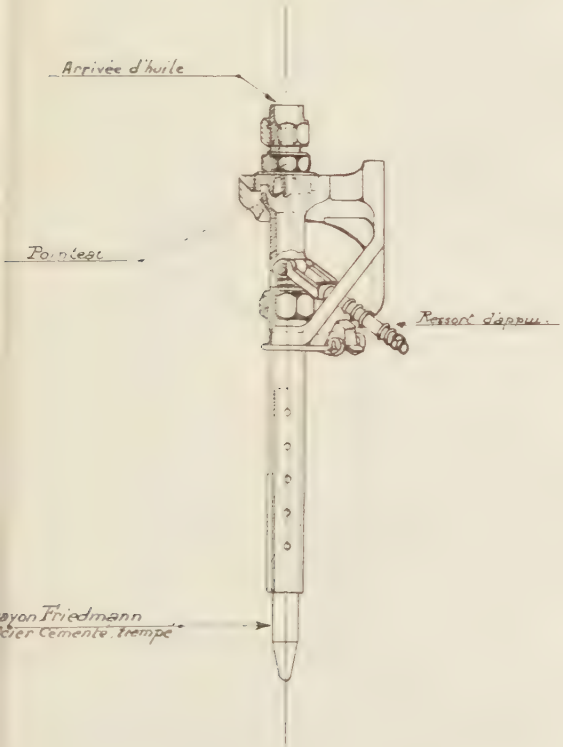


Fig. 21*b*. — « *Friedmann* » feeler (*Swiss Federal Railways*).

Arrivée d'huile = oiling point. — Pointeau = feeler. — Ressort d'appui = bearing spring. — Crayon Friedmann acier cementé, trempé = Friedmann rod, case hardened and tempered steel.

The tank is fixed to the bogie frame. The air pressure is constantly maintained by a valve at 5 kg/cm² (71 lbs. per sq. in.). The vaporiser has dual adjustment to provide a suitable mixture of air and oil. The orifice for projection onto the rail is adjustable so that only the vertical face of the rail head is sprayed by the jet;

b) The lubrication device fitted to the metre gauge diesel locomotives of the Tunisian Railways is actuated by the rotation of the bogie in relation to the body when entering the curve. It comprises :

— a 9 litre tank, containing oil under air pressure, located inside another tank containing water heated by the diesel engine cooling system to make the oil more fluid;

— a 3-way distributor cock with the base fixed to the bogie and the handle rigidly linked to the body of the locomotive allowing a rotation of between 12° and 80° from the neutral position;

— two « Riboulet » extendable tubes located on the side for each rail and fixed to stretchers on the roller bearing axleboxes; according to the displacement of the bogie in relation to the body the distributor valve feeds one or other of the tubes. As the linkage of the body and valve is adjustable, lubrication can be limited at will to any degree of curvature. Oil is sprayed on the rail as an emulsion of oil and air, with a controlled mixture;

c) *the « Lubrovia » lubricator* was fitted by the French National Railways following trials undertaken in 1947; it is on trial or

under consideration by several other Administrations (Algerian, French Light, Cameroons, Luxemburg Railways).

A description of this device was included in an article by MM. LAFAYE and VORBURGER (1) (fig. 23).

Lubricating oil contained in a tank and the compression element (air or steam) are admitted automatically when running on a small radius curve, by a distributor to an atomising ejector located near the outer rail of the curve. The pulverized lubricant is sprayed on the upper radius portion on the inside of the latter rail. There is

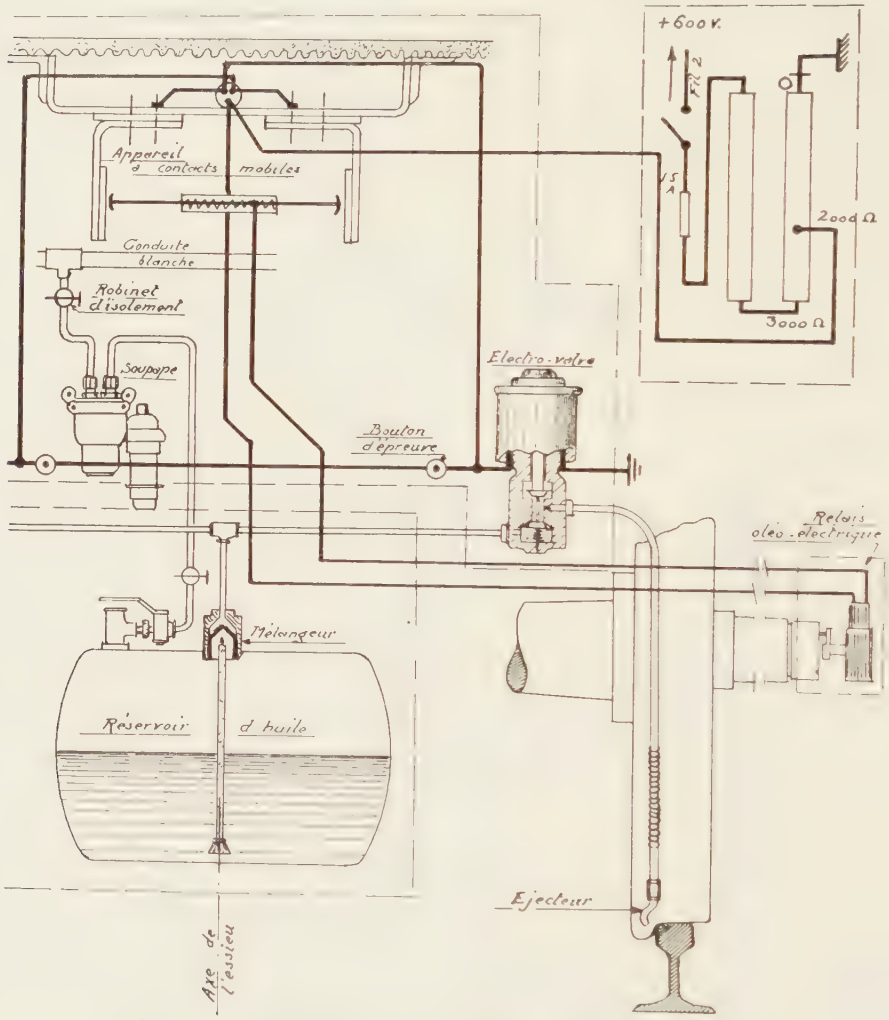


Fig. 22. Automatic rail lubricator, on bogie (*R.A.T.P.*).

Appareil à contacts mobiles = apparatus with adjustable contacts. — Conduite étanche = free pipe. — Robinet d'isolement = isolating cock. — Soupape = valve. — Mélangeur = mixer. — Réservoir d'huile = oil tank. — Electro valve = electro-valve. — Bouton d'épreuve = test button. — Relais oléo-électrique = oleo-electric relays. — Ejecteur = ejector. — Axe de l'essieu = center line of the axle.

(1) *I.R.C. Bulletin*, August 1952, p. 595.

a distributor ejector assembly for each line of rail. Opening and closing of the feeds for oil and compressing agent are obtained in each distributor by an oscillating cam controlled by a rod operating under the relative movement of the locomotive frame members.

This apparatus has a low degree of inertia, distribution is reasonably precise and the tubes are practically invulnerable;

d) Finally mention may be made of a simple *sprinkler* for the inner face of each rail by means of a feed from the tender of a steam locomotive.

Maximum radius of curves lubricated.

When lubrication is effected by equipment fixed ,or located on, locomotives and adjusted to operate at a given radius, the value of the maximum radius varies greatly between Railways :

Standard gauge :

Netherlands Rys.	1 500 m
Belgian National Rys. (S.N.C.B.).	1 200 m
French National Rys. (S.N.C.F.) .	600 m
Algerian Rys.	300 m
R.A.T.P. { suburban	400 m
R.A.T.P. { metro	250 m
German Federal Rys	200 m

Metre gauge :

Algerian Rys.	300 m
Tunisian Rys.	300 m

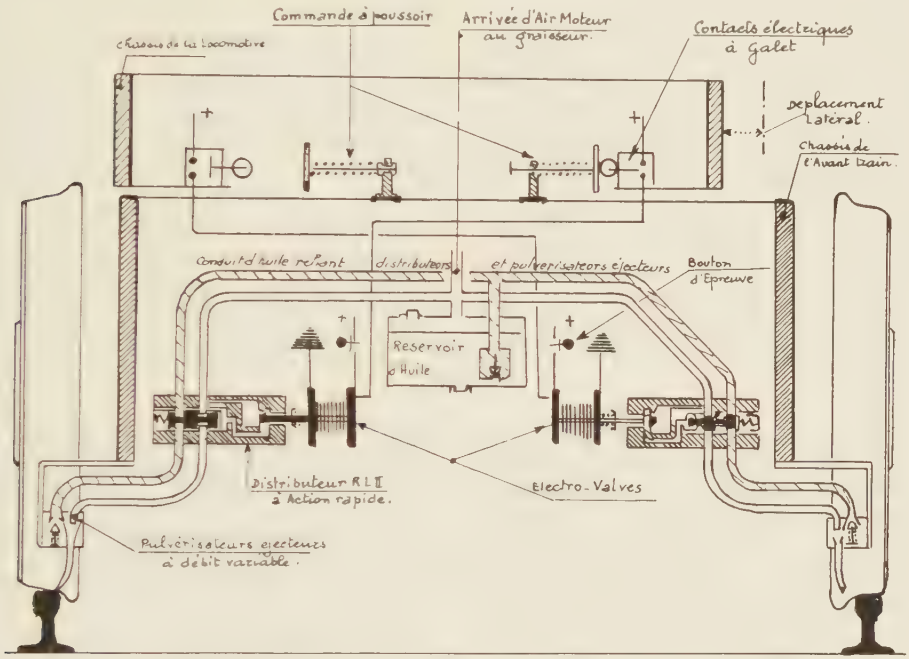


Fig. 23. — « *Lubrovia* » automatic rail lubricator.

Châssis de locomotive = locomotive frame. — Commande à poussoir = push button control. — Arrivée d'air moteur au graisseur = air input to lubricator. — Contacts électriques à galet = electric roller contacts. — Déplacement latéral = lateral displacement. — Châssis de l'avant-train = frame of leading bogie. — Conduit d'huile reliant distributeurs et pulvérisateurs éjecteurs = oil pipe linking distributors and atomising ejectors. — Bouton d'épreuve = test button. — Réservoir d'huile = oil tank. — Distributeur RLII à action rapide = RLII quick acting distributor. — Pulvérisateurs éjecteurs à débit variable = variable delivery atomising ejectors. — Electro-valves = electro-valves.

Cameroons Rys.	250 m
Viet-Nam Rys.	200 m
Madagascar Rys.	100 m

On very sinuous lines with curves of low radius it is considered by several Administrations unnecessary to have automatically operated lubricators in curves below a given radius. The Swiss Federal Railways consider that any resulting economy of lubricant would not offset the cost of maintenance and that it is preferable for convenience, as well as technical reasons, to undertake continuous lubrication of the track (wear of rail cheeks and flanges being produced in all curves and even on straight sections because of hunting movement); to compensate for the sinuousness of the track, a greater or smaller number of engines can be equipped with lubricating devices and their action supplemented by other processes (lubrication of flanges at the shed or by fixed equipment).

Products used for lubrication.

a) Manual rail lubrication is generally carried out with a mixture of graphite and oil in a ratio varying from 1 to 4 (German Federal Rys.) to 1 to 2 (Madagascar Rys.). The quantity used varies from 10 tot 15 up to 80 kg (22 to 33 up to 176 lbs.) per km of rail lubricated per year, according to the quality of oil used (new or recovered) and the amount of traffic.

For brush application to flanges the Swiss Federal Railways use a mixture of decanted black axlebox oil and powdered graphite.

b) *Fixed lubricators.*

— « P & M » lubricators : Caltex 904 grease (petroleum 70 %, graphite 15 %, limed soap 15 %). No special distinction is made for hot or cold seasons of the year. The quantity used varies on different regions from 28 to 60 kg (62 lbs. to 132 lbs.) per km of rail concerned per annum; it reaches 300 kg (661 lbs.) on lines with heavy traffic and low radius of curvature on the Belgian National Railways. It has an average of 0.4 g per axle per km of track lubricated on various secondary lines of the French National Railways.

— Paehler lubricator : oil recovered from the repair shops used in winter to —8° C with the addition of 20 % petroleum to —15° C. Consumption which involves no expenditure is 160 kg (353 lbs.) per annum for two installations per km of rail lubricated on heavily worked lines.

c) Flange lubricators on engines :

— Limon equipment : Shell high pressure grease (at present 1.2 to 2.2 kg per 1 000 vehicle-km); this quantity tends to decrease as the number of equipments installed is increased:

— Swiss Federal Railways equipment : recovered axlebox oil, decanted but not filtered. Some pumps with more delicate equipment use fresh dynamo oil, with higher viscosity, which can be diluted in winter with equal quantities of petroleum:

— Bertschmann lubricator : 25 g of oil per 100 km of rail.

Buclon lubricator and air ejector : 1/7 g of oil per locomotive axle running per km lubricated.

Graphite rods on Matadi-Leopoldville Railway : 1.1 rods per 1 000 km run.

d) Rail lubricators on engines

— Lubrovia equipment : STU No. 178 machine oil with addition of burning oil when temperature is lower than +15° (5 % at +15°, 20 % at —30°); consumption 0.133 to 2.267 g per axle per km lubricated.

— R.A.T.P. equipment : G. 75 oil (R.A.T.P. technical specification C. 1) 365 g per axle per km lubricated:

— Tunisian Railways : oil drained from Diesel engines, subject to simple decanting; no special distinction between summer and winter, the oil being re-heated in the tank by the water from the motor cooling system at a temperature of 70 to 80°; delivery 0.05 litre per minute. The quantity of oil used per km of rail lubricated depends on the speed of the train and the viscosity of the mixture.

Advantages and disadvantages of the methods and equipment used.

a) Hand lubrication of rails is normally justifiable because of the high labour cost only when it is limited to a few curves of very small radius. Whilst certain hand equipment, such as that used by the Madagascar Railways (Guenneguez, Biberon) for the past six months are satisfactory, brush application must, by its lack of precision, entrain the risk of oil spreading on the tread of the rail. Further, the Tunisian Railways have abandoned it because it causes slipping, particularly on gradients. The use of equipment mounted on trolleys and operated by hand offers the same disadvantages.

Hand lubrication of flanges by brush, as systematically used by the Swiss Federal Railways on locomotives leaving a shed gives satisfactory results.

b) Fixed lubricators have the advantage of greasing each flange, which lubricates the rail. Administrations using them, particularly the « P & M », « Aladdin » and « Paehler » are satisfied with them. Grease, however, is plentiful near the equipment, but spreads only slowly along the inner face of the rails; as each unit acts only on relatively short lengths of track, they must be multiplied to give satisfactory results.

The following distances over which lubrication is effective, are reported by some Railways :

German Federal Rys.		200 to 500 m
Italian State Railways	« P & M » about	900 m
	« Aladdin » about	900 m
	« Racoor 4 000 » about	15 km

The German Federal Railways report that the use of graphite avoids the danger of the lubricant spreading to the running surface, which occurs with oil alone. Finally, certain Administrations state that refilling with grease is fairly laborious and frequent.

c) Flange lubricators of felt pads as still used on some vehicles (Swiss Federal Rys.) may cause oil smears on the tyre tread; they are to be taken out of service.

« Buclon » lubricators spread an insufficient quantity of oil and suffer from a polishing of the leathers which limits the delivery or stops it (Madagascar Railways).

Air or steam ejectors, also used by the Madagascar Railways, grease the flange according to the movement of the axle and it is necessary to shut them off when standing; moreover the operation of air ejectors demands the use of a more fluid oil to give efficient lubrication.

Feelers of the Friedmann type, and those used for metre gauge coaches, whose simplicity of installation and operation must be emphasised, are amongst the arrangements which have given the Swiss Federal Railways the best results out of 60 methods of lubrication which they have tested or investigated.

d) Rail lubricators fixed to locomotives or rolling stock, formerly used by the Swiss Federal Railways, projected the oil with too little accuracy on the side of the rail, the ejector was deformed by striking obstacles (track ballast or foreign bodies) which deflected the spray of lubricant; this caused skidding. The lubricators used by the Portuguese Railways for a long time had similar defects and in addition the adhesion of sand to the oil on the rails and tyres caused abrasion. The Matadi-Leopoldville Railway has also abandonned this device because of its inaccuracy.

On the other hand, equipment at present in use by several Administrations operates in a satisfactory manner, causing no skidding or disturbance of electrical circuits. Lubrovia lubricators are generally preferred by the French National Railways to fixed lubricators as they lubricate all

curves affected by the motive units and all axles of the train benefit by the film laid by a single device; in addition, experience shows that it is useless to equip all engines and it is sufficient that the ratio of the number of trains daily to the number of locomotives equipped should be less than 6 to give satisfactory results.

The R.A.T.P. points out the advantage of precise and uniform distribution all along the rail of the curve of a thin film of oil, renewed by the lubricating vehicle after the passage of about 320 axles.

The Tunisian Railways, who had obtained excellent results with the former lubricators mounted on steam locomotives, consider that similar results will be obtained with the new equipment used on their metre gauge Diesel locomotives; greasing by the passage of one of them lasts about 48 hours for a traffic of 20 to 30 trains per day of 10 000 gross tons (or for about 50 trains).

Price and annual costs of various equipment.

As the information provided differs fairly considerably according to the country, particularly as regards the labour charges, the following estimates in French francs can give only the order of the amount :

	Installation cost Francs	Annual charge for consumption and maintenance. Francs
Fixed lubricators		
Paehler	25 000	16 000 per unit.
P & M	43 000 to 64 000 (aver. 50 000)	from 10 000 to 25 000 per unit.
Racoor 4 000	300 000	
Lubricators mounted on locomotives :		
Bertschmann	10 000	
Limon	110 000	7 000 to 36 000 per loco. plus 125 fr. per 1 000 km-vehicle.
Lubrovia	190 000	75 000 per locomotive.
Tunisian equipment RATP	72 000	150 000 per year for 24 000 km of curved track
Graphite rod (Matadi-Leopoldville Ry.).		430 per 1 000 km run.

As an example, the French National Railways has compiled the following annual cost of lubricating a given line, firstly with a P & M lubricator and secondly with a Lubrovia lubricator mounted on a locomotive, the equipment being assumed to have a 10 years life :

a) with P & M lubricators (48 required for the line) per unit :	
Sinking fund : 1/10 × 50 000 fr.	5 000 fr.
Material and maintenance	10 000 fr.
	15 000 fr.
for 48 units : 15 000 × 48	720 000 fr.
b) with Lubrovia lubricators (one locomotive in 5 or 4 per 20 trains) :	
Sinking fund : 1/10 × 190 000 fr.	19 000 fr.
Material and maintenance	75 000 fr.
	94 000 fr.
for 4 units : 94 000 × 4	376.000 fr.

Results obtained by rail lubrication.

The results obtained affect not only the rails themselves but also tyres and traction energy.

a) *Wear of rails.* — All Administrations which use lubrication agree that it provides a noteworthy reduction in lateral wear of rails on the larger radius of curves, and that scoring and grinding are eliminated.

On certain Railways experience is yet too recent to provide exact economic results. On the R.A.T.P., on the contrary, curves of low radius have always been lubricated to avoid grinding and rapid wear, and it is not possible to pin point the resulting reduction in wear. We may, however, note the following information.

The reduction of lateral wear is estimated at about :

25 % on the Belgian Railways;

40 % on the Netherlands Railways;

33 % on the German Federal Railways (on irregular or sinuous track);

50 % on the Tunisian Railways (from lubrication undertaken since before 1939, the life of rails has been doubled).

On the Algerian Railways, lateral wear which was about 1 mm per three months has been reduced to 1/3 or 1/4 of a mm.

The French National Railways mention that in curves of less than 500 m radius, rails had normally to be replaced at a rate almost twice the normal rate; if the use of lubricators eliminates this need, the annual saving can be assessed per km of curve less than 500 m radius at about 20 000 fr. for 45 kg (99 lbs.) rails with a probable life of 100 years on the secondary lines considered. The Tunisian Railways estimate a figure of 20 000 fr. per km annual saving in rails on a line comprising 5 % of low radius curves whose life is doubled by lubrication of the outer line.

b) Wear of tyres. — All Administrations consider that lubrication has the effect of reducing this wear.

The Belgian National Railways note a reduction in sharp flanges. On the French West African Railway the life of tyres is almost tripled. On the German Federal Railways it is 1 1/2 to 2 times higher on locomotives fitted with the Limon equipment.

On the ten 141 E locomotives at the Langeac Shed (S.N.C.F.) for example, with a period of 8 months, the total tyre returnings dropped from 36 to 10 and tyre changing on leading bissel trucks from 7 to 2 after installation of Lubrovia lubricators; the cost, previously 960 000 fr. was reduced to 104 000 fr. to which must be added capital charges, maintenance and consumption of oil. Savings have been assessed at more than 400 000 fr. per annum.

The « Régie Autonome des Transports Parisiens » report an assessed saving of 20 % in tyre consumption and work of changing corresponding to an annual saving of 18 million francs together with re-

duction of operating difficulties or accidents consequent upon flange wear.

The Swiss Federal Railways, on the Brunig metre gauge line had formerly to re-turn tyres every 6 000 km (3 730 miles), but after the simultaneous introduction of flange lubrication and transverse coupling of bogies, the returning period has been increased to 120 000 km (74 560 miles) or 20 times greater. On shunting locomotives, the mileage without re-turning has been increased sixfold. It is also stated that if flange lubrication on the Brunig line is stopped, its effect can be cancelled in one day, and it requires weeks to bring to an acceptable condition the worn rails and flanges.

c) *Economy in traction energy.*

Most Administrations do not provide any information on this. The Swiss Federal Railways recall that the reduction of resistance to running in curves was the main purpose of the first flange lubrication trials, which date from 1850. Some Administrations consider it impossible to evaluate (German Federal Rys., Italian State Rys.). The French National Railways consider the reduced resistance to running in curves gives a saving of 10 % in traction energy for equal loads hauled.

SUMMARIES.

1) Lateral chamfering wear of rails on the outer side of curves is particularly noticeable in curves of less than 500 m (250 chains) radius on standard gauge and 350 m (17 1/2 chains) on metre gauge lines. It can vary within the length of one rail. The running surface of rails is also frequently subject to wear on a plane inclined towards the centre of the track.

Wear of the inner line of rails is by flattening of the running surface, often accompanied by a spread of metal with the formation of burrs.

The finish of the surfaces in contact is mostly retained.

Binding is sometimes experienced during the passage of an axle, with grinding, fall of scrappings or even stripping of narrow strips of metal.

2) The main characteristics of track laid on a curve, having a predominant influence on the wear of curved rails are as follows :

a) small radii and their relation to speed of operation;

b) excess or deficiency of superelevation;

c) steep down-gradients;

d) excessive or insufficient width of gauge;

e) insufficiently long parabolic curves;

f) irregularities of lay-out or level of the track, or faulty behaviour of fastenings.

3) The following features of rolling stock are considered to have a predominant influence on the wear of rails :

a) excessive or insufficient length of rigid wheelbase, which governs the angle of attack by the flange on the guiding rail;

b) the stiffness of the bogie or bissel side control;

c) abnormal lateral or longitudinal play allowing excessive angle of attack;

d) excessive unsprung masses, or inflexible suspension;

e) wheel diameter (lateral or vertical wear predominating, according to whether the diameter is greater or less).

4) The driving bogies are often considered as being particularly aggressive in curves, producing heavier lateral wear on the outer line of curved track than carrying bogies and certain long-wheelbased vehicles. This wear is particularly noticed at turnouts, entrances to curves and at track irregularities.

The effects of wear due to driving bogies are attributed mainly to the heaviness of the axles, particularly unsprung masses, the gyroscopic effect of rotating parts, the sometimes difficult inscription due to the link between axle and motor, the tractive

effort which tends to increase the angle of thrust.

5) To increase the life of rails, steps are being taken to :

— reduce gauge widening, modify super-elevation and sometimes stagger joints;

— reverse rails end to end, change from one side to the other, or relay on straight track.

6) A check rail is sometimes laid along the inner line of very short radius curves, not only to reduce lateral wear of outer rails but also to increase safety.

7) The most efficient methods of reducing wear of rails in curves are : the use of high-resistance steels and lubrication of the inner side face of rails on the larger radius.

8) Naturally hard rails of a single grade of steel; rails with heads heat-treated (sorbitic or martensitic) on their whole length or only at both ends; rails in compound steel in which only the wearing surface of the head is of hard steel, are used in low radius curves with heavy traffic. Their resistance to wear usually allows a much longer life than rails of ordinary quality.

9) The lubrication of the inner face of the head of rails on the outer line is current practice. It provides a considerable reduction in lateral wear of rails, estimated to be in region of 30 to 50 %.

Manual lubrication is limited to special cases, because of the labour costs involved; the work must be carried out with care, to avoid the oil spreading on to the running surface.

Fixed lubricators and devices mounted on motive units or trailer vehicles, as now designed, provide satisfactory regularity of operation.

The use of fixed lubricators is justified on isolated curves of low radius or where they are relatively few on a given line.

The apparatus used for lubricating the rails or the wheel flanges mounted on the motor units or trailing vehicles are more economical on lines with fairly numerous curves; it is generally advantageous if lubrication is automatically applied at the development of short-radius curves, except on very sinuous lines, where lubrication can be continuous.

[656 .257]

INTERNATIONAL RAILWAY CONGRESS ASSOCIATION

16th. SESSION (LONDON, 1954).

QUESTION 6.

A) Remote operation of signal boxes : technical realizations, working orders.

B) Electric working and control devices for hinged and « flexible » points and switches. Control of accidental trailing of the switch blade.

REPORT

(Belgium and Colony, Spain, France and French Union, Greece, Italy, Luxemburg, Netherlands, Portugal and Colonies, Switzerland, Syria and Turkey),

by J. NOGUÉS,

Deputy Manager, Spanish National Railways.

A questionnaire was sent out to 60 Managements in the above mentioned countries, from 30 of whom replies were received.

Those mentioned in Chapters I and II hereafter provided very interesting information and gave particulars which proved most useful in the preparation of this report. They will be summarised and commented upon in the corresponding section. Sixteen other Managements stated that they were unable to furnish the information asked for, in view of their lack of experience of the special types of installation covered by question 6.

This question covers under the headings *a*) and *b*) two very different subjects and for this reason the report will be divided into two Chapters : I, Remote control of signalling installations, and II, Electric working and control devices for hinged and « flexible » points and switches.

We shall follow the order of items as set out in the questionnaire in order to facilitate comparison between the various reports and the task of the special reporter. A summary at the end of each chapter will give the general views which emerge from a study of the replies received.

CHAPTER I.

A. — Remote control of signalling installations.

A remote control of signalling installations.

The Managements which replied in a positive manner to this part of the questionnaire are :

Belgium :

Belgian National Railways Company.

Office d'exploitation des Transports coloniaux (« OTRACO »).

Spain :

Spanish National Railways.

France :

French National Railways Company.

Italy :

Italian State Railways.

Switzerland :

Swiss Federal Railways.

The subject of this chapter was included in Question IX (Section III) of the Rome Congress (1950). The subject of « remote control » however as it is now worded, must here be looked at from a point of view distinct from that taken at the time of the 1950 Meeting.

It is now a question of the *technical arrangements* used to effect the remote control but previously it was the traffic operating aspect of the matter, the applications and results obtained with remote control that was under consideration. However, the reporters thought it necessary to continue the general investigation of the question. The fact that Question 6 has been grouped under Section III and not Section I seems to confirm that the operating aspect of remote control has to be taken into consideration concurrently with the technical. This is the explanation of the contents of the Questionnaire which was sent out, and very fully and carefully replied to by the Managements above mentioned.

QUESTIONS 1, 2, 3 *a*), *b*), *c*). — *Form of remote control installations put into service : reasons for adopting a particular type of construction.*

The number of remote control installations carried out since 1950 in the countries concerned is very small. Nevertheless, despite the replies received, there appears to be a tendency to increase the use of remote control. Two groups of such installations are to be considered, viz :

a) Centralised traffic control (known as C.T.C.) with remote control of signals and points at stations throughout a section of single, double or multi-track line, with or without reversible working on any particular track.

b) Remote control from a neighbouring station of points and signals in areas around large stations, or at junctions, crossing loops, etc.

We summarise below the replies received to Questions 1, 2, 3 *a*), *b*), *c*) in groups in accordance with the preceding classification.

a) *Centralised traffic control (C.T.C.).*

Belgium.

The S.N.C.B. states that up to now in Belgium no case has arisen where remote control of several stations had to be considered in order to allow of increased traffic. As regards any reduction in staff which such working would make possible, the S.N.C.B. considers that account has to be taken of the fact that staff have to be on duty at stations, not only to operate points and signals but to perform other functions in connection with the traffic which C.T.C. does not do away with.

« OTRACO » has decided to apply C.T.C. to its single line between *Matadi and Leopoldville* (365 km [227 miles]) for the following reasons : 1° increase of about 80 to 100 % in the traffic capacity; 2° avoidance of having to double the line on sections where there are gradients and postponement of doubling elsewhere; 3° placing the control of the traffic working throughout the line in the hands of white staff. It is pointed out that the saving in staff will be relatively small. The stations have only one through track and a loop, remotely controlled. Each is divided into two areas, so controlled, arranged as shown on diagram 1 attached to the questionnaire (see Table No. I).

Spain (RENFE).

The C.T.C. installation to be brought into use in September 1953 (see fig. 1) serves principally to increase the traffic capacity required to deal with the expected great growth of production from the min-

TABLE I. — Centralised traffic control (C.T.C.) installations

MANAGEMENT	*Belgium* OTRACO	*Spain* RENFE	*France* SNCF	*Italy* F.S.	
Route covered	Matadi-Leopoldville	Brañuelas-Ponferrada	Blaisy-Dijon	Genoa-Rome line	Bologna circular line (group of junctions)
Number of tracks	Single	Single	double, for either direction working	Single	double
Length of line controlled	365 km	49 km	27 km	14 km	55 km
Amount of traffic	521 million ton-km.	45 trains daily	120 to 180 trains daily	80 trains daily	400 trains daily
Number of stations	37	8	3	8	10 junctions
Number of C.T.C. locations	74	14	9	—	—
Number of functions at the principal location.	4 points 6 signals	6 points 8 signals	—	—	16
Total number of functions controlled by C.T.C.	333	31 ponits 61 signals 6 electric locks	38 points 53 signals	—	160
Distance from central apparatus to farthest location	365 km	49 km	15 km	—	15 km
State of completion April 1953	1/3 in course of construction	ready to go into service	in service	being planned	Work well advanced towards completion

ing area served by the section at single line between Ponferrada and Brañuelas, where there are heavy gradients. C.T.C. will assist in increasing capacity by eliminating the waste of time between the giving of an order by the Traffic Controller (or Dispatcher) and its execution by the stations, and by providing quicker and more complete information on the position of the trains. Automatic block and electric traction are to be introduced on this line.

In addition it is hoped to realise with the C.T.C. installation important savings of traffic staff at the stations, some 40 persons in all. The characteristics of the through running stations concerned appear to be favourable to doing that on a very extended scale.

The stations have either one or two loops, remotely controlled, and at each there are two subsidiary apparatus locations, arranged according to the diagram No. 1 attached to the questionnaire.

France :

Remote control over a section of line has recently been applied by the S.N.C.F. between *Blaisy* and *Dijon* to allow of each track of a double line being used for traffic in either direction, thus avoiding having to put down another track of two more tracks (see Table I). The S.N.C.F. thinks that short of circumstances of this kind, C.T.C. is not justified on the grounds of reduction of staff alone — economies which may be obtained on lines equipped with automatic signalling and no remote control — and its application should only be contemplated in the very exceptional cases of lines which have reached their traffic saturation point, that is to say, carrying over 70 movements daily on single or 160 to 200 on double lines. In the latter case the benefit to be gained from applying C.T.C. is a function of the number of slow trains that have to be moved out of the way of other trains requiring to overtake them.

Fig. 1. — Control panel and desk of C.T.C. installation on the Brañuelas-Ponferrada line.

Figure 2 shows the area under the control of the C.T.C. post at *Dijon* and the arrangement of signals and line worked by it.

Italy (F.S.).

The Italian State lines are to instal C.T.C. to cover a single line bottle neck of 17 km (11 miles) on the main Genoa-Rome double line, with peak traffic of 80 trains daily. The object is to effect the necessary

increase in capacity in order to avoid doubling, very difficult to carry out. The Management emphasis that the capacity of a single line is principally determined by the number and suitable location of the crossing places.

C.T.C. is being installed on the double track lines serving the group of junctions around Bologna (Bologna circular line) a frequent service of trains following each other at different speeds.

b) *Remote control from a neighbouring station of points and signals in areas around large stations, or at junctions crossing loops, etc.*

France (S.N.C.F.).

The S.N.C.F. has applied remote control to

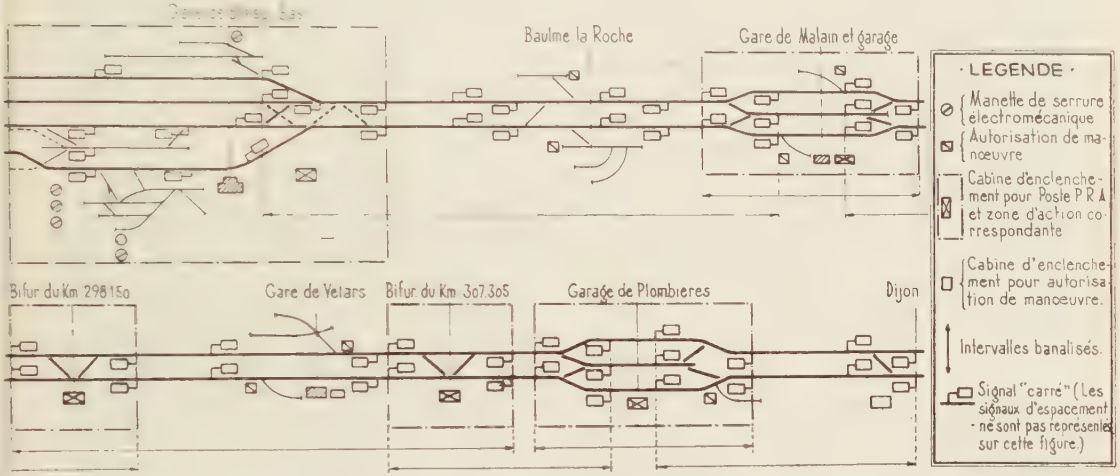

Baulme la Roche
Gare de Malain et garage
Bifur du Km 298 150
Gare de Velars
Bifur du Km 307.305
Garage de Plombières
Dijon
· LEGENDE ·
Manette de serrure électromécanique
Autorisation de manœuvre
Cabine d'enclenchement pour Poste P.R.A. et zone d'action correspondante
Cabine d'enclenchement pour autorisation de manœuvre.
Intervalles banalisés.
Signal "carré" (Les signaux d'espacement ne sont pas représentés sur cette figure.)

Fig. 2. — Diagram of the section Blaisy-Bas—Dijon, with C.T.C. allowing each track of a double line being used for traffic in either direction.

Explanation of French terms:

Manette de serrure électromagnétique = electromagnetic lock hand lever. — Autorisation de manœuvre = shunting permission. — Cabine d'enclenchement pour poste P.R.A. et zone d'action correspondante = interlocking-box for P.R.A. post and corresponding action area. — Cabine d'enclenchement pour autorisation de manœuvre = interlocking-box for shunting permission. — Intervalles banalisés = sections in common use. — Signal « carré » (les signaux d'espacement ne sont pas représentés sur cette figure) = « square » signal (spacing's signals are not shown on this fig.).

(see Table I). We have classed this among the C.T.C. installations controlling a complete length of line, but from the particulars furnished we consider it bears relation also to the characteristics of group *b*).

The F.S. point out that C.T.C. on double lines offers the greatest interest when it is a question of applying reversible working on fairly extensive sections, having cross-over connections suitably located. The possibility of deriving noticeable results depends however on the traffic having certain quiet periods on one of the tracks and combine into one signal box or operating location, the control of installations extending over a considerable area. In such cases this arrangement allows of reducing the very considerable expense ordinarily required for cables and wiring and of obtaining the advantages afforded by bringing a number of controls together, as well as of effecting a saving of staff. The Montereau signal box, which controls 119 sets of points and 340 routes, has taken the place of 5 mechanical boxes. It controls 4 zones. One is dealt with by « direct » control, the

three others by remote control. The greatest distance between the signal box and a remotely controlled function is 9 km (5.6 miles).

Belgium (S.N.C.B.).

The S.N.C.B. attaches great importance to remote control as a means of extending economically the area of control of a signal box and bringing within its action installations located some distance away, such as junctions placed a certain way from stations. With this in mind it has applied remote control to the junction of Soignies on a double track line. The subsidiary apparatus location is 3.6 km (2.2 miles) distant from the signal box, and the following are remotely controlled :

signals	6
points	2
point heaters	2
outdoor lighting fittings	1.

Italy (F.S.).

The F.S. considers that there is benefit to be gained from remote control for groups of junction layouts from the point of view of reducing operating costs and cable installations costs.

The Bologna installation above mentioned is being put in now. Table I gives its chief features, the mixed character of the installation being borne in mind.

It covers 10 junctions and in addition remote control is used to send certain releases to 6 through running stations, to Bologna Central Station, to the marshalling yard at Bologna (S. Donato) and two other freight yards.

Switzerland (C.F.F.).

The remote control of the cross-over signal box in the Simplon tunnel (double line) is in course of installation and will include 4 points and 4 signals. The question of applying such control to a single line crossing place with 4 signals and 2 points is being considered.

The C.F.F. advise us that they have in service 5 remotely controlled installations, covering automatic signals, with axle counter control, worked from the adjacent stations.

QUESTION 3, *d*). — *How are the block sections situated between the different telecontrolled stations operated ?*

e). — *Do you provide emergency signals for the station signals and block posts of an absolute or non permissive character and how are these signals operated (by the train staff, the head of the central post) ?*

All C.T.C. installations here described have automatic signalling working with them. Generally speaking the occupation of each block section is repeated on the diagram or panel at the central control point. In the case of the RENFE the approach sections are separately so indicated, but all the other intermediate sections between stations are repeated by a single indication, if there are several between two approach sections. In the « OTRACO » installations only the approach sections are indicated on the diagram.

The signals are absolute, in the case of sections containing any points and permissive in other cases. Generally both the « off » and « on » indications of absolute stop signals are repeated on the diagram; proving of the stop indication is effected locally. In Belgium the « off » indication is repeated and the « on » indication proved in the signal box. In Spain the « off » indication is indicated only in the case of remotely controlled signals.

In the countries concerned here only absolute stop signals are remotely controlled as far as that indication is concerned, the remaining indications being dependent on the automatic signalling controls.

None of the managements, whose opinions have been obtained, uses emergency or draw-ahead signals (authorising a driver to pass a stop signal at danger).

QUESTION 5. — *What is the capacity of the telecontrol system adopted, as regards the number of Local Posts which can be controlled and the number of apparatus which in each local post can be operated and controlled from the Central Post? Does the fact that the Central Post is situated or not at the extremity of the route affect its capacity.*

The telecontrol systems used with C.T.C can operate and prove the working of a number of subsidiary locations, up to a predetermined maximum. As the number of such locations increases the number of appliances at each one that can be controlled diminishes, as does the number of return proving indications that can be transmitted back to the central apparatus. In the systems used in Spain and Italy (20 impulses) the capacity when the control point is at one extemity of the sections is as follows :

Number of subsidiary locations	*Number of outgoing controls per location*	*Number of return proving indications per location*
1	10	20
2	9	19
4	8	18
8	7	17
16	6	16
32	5	15
64	4	14

If the number of locations is contained within two values in the first column, some of them may have more controls going to them than shown in the second column. For instance, one can have 60 locations, each with 4 controls, plus one more with 6, or two more with 5 each.

If the control point is not at one end of the line, the maximum capacity above can be obtained by adding the panels and units required by each location.

The S.N.C.F. uses a system having a maximum capacity of 35 groups each comprising 7 controlling and 7 return proving indications per group. These 35 groups can be allocated according to the requirements of the locations to be served. In the *Dijon—Blaisy-Bas* installation, the line is divided into three zones in order to provide the desired flexibility and speed of operation. Each is served by a distinct separate line circuit and set of equipment.

The system applied by the S.N.C.B. has a capacity of 12 × 7, 28 × 7 or 35 × 7 controls and an equal number of return proving indications, capable of being divided as a maximum among 12, 28 or 35 different locations. The position of the control point is without influence on the capacity of the system.

For other applications of remote control the S.N.C.F. uses a system of its own, in which the number of subsidiary locations and items of apparatus controlled is theoretically not limited (1). In practice the equipment has been arranged to provide a maximum of 3 600 controls, which may be allocated at will among any desired number of subsidiary locations. The number of controls per location is also unlimited, in theory. In practice, however, the limit placed on the time that may be taken to transmit a control sets in turn a limit of 100 controls per second.

The C.F.F. (Switzerland) at present use a remote control system capable of transmitting 25 controls. This number can easily be increased to 100. The number of appliances that can be remotely controlled depends on the number of positions of each that are required to be controlled and proved.

QUESTION 6. — *What distance can you cover with your system of telecontrol without having to use installations with a carrying frequency?*

The transmission of remote control to any considerable distance has not been in question in the case of the Managements furnishing us with information. In the systems in use for C.T.C. the theoretical maximum distance without resorting to relaying circuits,

(1) See the description by M. Walter in the *Bulletin of the International Railway Union*, April 1948.

appears to be of the order of 200 km (125 miles). (The S.N.C.F. mentions 70 km [43 miles]). In general, however, it is found in practice that the distance that can be dealt with depends more on the number of locations and appliances to be operated, as far as the number of available codes is concerned, than the maximum distance to be covered.

In other cases the distance practically workable may be limited by reasons of rapidity and flexibility, that is to say when the amount of traffic is very considerable, the time required to transmit the various codes can give rise to objectionable delays in sending them out.

QUESTION 7, *a*). — *What type of transmission do you generally use for the operation and control (A.C., D.C., sound selection, induction selection, wireless or other)?*

All the managements consulted use D.C. impulses except the C.F.F., which use A.C.

7, *b*). — *How many impulses are there in the code used? Do these impulses differ in frequency, in polarity or in duration?*

It is to be noted that most managements reckon the number of impulses as the sum of the interruptions and restorations of the current which make up each code, when impulses of different length are involved.

In Belgium and France, a 16 impulse system is used for C.T.C. In Spain and Italy a 20 impulse system is found. The impulses in each code vary in length in Belgium, Spain, France and Switzerland. In Italy, the control impulses vary in polarity. The original remote control system of the S.N.C.F. is formed of one or two series of 3 impulses, differing by their polarity and the line wire over which they are transmitted.

7, *c*). — *Do you use a coded system with a chain of relays or a rotary selector?*

All the Managements concerned use chains of relays. In the S.N.C.F. system the remote control is effected by synchronised relay chains which are used to make a cyclic exploration of the local control circuits after the manner of rotary selectors.

7, *d*). — *Is the transmission line under tension or not under tension when it is not transmitting? Are the insulation and continuity of the transmission line permanently controlled by the Central Post?*

The transmission line is normally energised in the remote control installations of the S.N.C.B., RENFE, S.N.C.F. (in the case of C.T.C. installations) but is not in the systems used by « OTRACO » and the F.S. When the line is permanently energised, that gives a measure of continuous detection of its state of insulation and continuity. When this is not the case such detection is afforded each time a code is transmitted.

7, *e*). — *Is the selector relay of each local post connected in series or in derivation on the transmission line?*

The selecting relay at each location is connected in series on the S.N.C.B., S.N.C.F. (in the case of C.T.C. installations) and F.S., and in parallel on the « OTRACO » and RENFE lines. In the S.N.C.F. system the line relays are connected in parallel and the synchronising relays in series on the special wire allocated to that function.

QUESTION 8. — *Are there any systems at a carrying frequency? (We are not concerned in this instance with the well known system in which the track is divided into various sections which are fed directly, and in which the furthest off sections are retransmitted onto the nearest circuits by means of the carrying frequency.) Are there any systems in which for example a different carrying frequency is given to each station or each apparatus?*

No Management consulted has made use of carrier frequency systems.

QUESTION 9, *a*). — *Is there interlocking between the points and signals —*

i) *at the local control post ?*

ii) *partly at the local post and partly at the central post ?*

iii) *at the central post ?*

In the countries, which have replied to this question, the interlocking between points and signals is always effected at the subsidiary location.

9, *b*). — *Are the points operated by setting up a route or can they be operated individually ? In the first case, do you consider that individual repetition of the working of the points is essential ?*

The replies received indicate that the points are generally operated as complete routes, except in the case of the RENFE installations, where signals and points are operated individually. In the first mentioned arrangement individual repetition of the position of the points at the central apparatus is held to be unnecessary.

9. *c*). — *In the case of shunting movements, are the points operated separately ? Are they then operated locally or from the central post ?*

Shunting is not involved in the case of the majority of installations under consideration here. In the RENFE, C.T.C. installations, the points are operated electrically on the spot when required for shunt movements under a release from the central apparatus. The giving of the release causes a white light to appear on the signal concerned, authorising the movement to pass it.

QUESTION 10, *a*). — *What operating and control apparatus is there on the panel of the Central Post and how are they arranged, geographically or in some other order ?*

Push buttons or rotary handles or knobs — also called thumb-switches — are used on the control panel. For the visual repeating and proving indications, small lamps of various colours are used. The insulated track section indications are arranged geographically on the panel, and the indications repeating the condition of the points and signals also appear on it or else in, or alongside, the actual operating button.

In the C.T.C. installation on the F.S. Bologna circular line, the apparatus comprises a panel for the automatic working, another for manual working, an illuminated diagram on which are repeated the points, signals and track circuit sections, and one showing the various routes on which it is possible to follow the movement of all trains in the area.

10, *b*). — *Are only the state of being in movement or the state of being out of order of the points signalled or else the position plus or minus of the blades of the point also transmitted to the central post ? If the points are accidentally trailed is this also signalled to the post ?*

As a rule the two extreme positions of the points are repeated on the central apparatus. The RENFE provides indications showing : 1° any discordance between points and the controlling switch or handle, and 2° when points are locked electrically. The S.N.C.F. indicates the correct working of the points or whether there is anything wrong with them.

QUESTION 11. — *How many conductors do you make use of in your telecontrol system (for operation and control) ?*

Do you make use of cables or overhead circuits (insulated or otherwise) ? What is the diameter or section of these conductors ?

Generally, a two core cable (10/10 or 13/10 dia.) is used, except on the RENFE where open insulated line wires are employed. The F.S. uses two wire circuits, one for the controls, the other for return

indicating and proving. The S.N.C.F. system used :

6 { 4 controlling and proving wires;
1 remote control or synchronising wire;
1 common return for the synchronising and return proving circuits.

QUESTION 12. — *What is the degree of user of these conductors? Can a pair of conductors be used simultaneously for the operation and control of different points and crossings?*

Are the same pairs of conductors used successively for operation and control, or are the lines only used for a single function? In what cases do you use more than a pair of conductors?

One 2-wire line circuit conveys in succession the controls and the return proving indications, except in *Italy* which uses separate wires for each function. (For the S.N.C.F. see Question 11.) More than one pair of wires are used on the heavily worked sections, when it is desired to increase the code capacity.

QUESTION 13. — *What measures of protection have you used on D.C. overhead telecontrol lines against disturbances and false transmissions caused by short circuits or atmospheric discharges in the case of storms, etc.? Or do you accept the risk of discharges in the case of storms occurring?*

In the case of the open line wires (on the RENFE and with the S.N.C.F. manual block system) the usual protection afforded by fuses and lighting arrestors is provided and the circuit is balanced.

QUESTION 14. — *Do you use D.C. transmission devices on electrified lines using A.C. supply, and how do you protect them from stray voltages?*

The S.N.C.F. has not considered it necessary with its coded manual block to take any special precautions. However, in order to protect the staff against induced voltages should the length of the transmission line exceed 8 to 10 km (5 to 6 miles) impulse relaying apparatus is installed. In Switzerland, the circuit is balanced and insulated from earth. This case does not arise in the other countries.

QUESTION 15. — *Over what distances do you make use of multiple user of the transmission circuits?*

The replies to this question are found amongst those dealing with Questions 6 and 11.

QUESTION 16, *a*). — *Are the operation orders and controls transmitted by a telecontrol installation limited in number, or is it possible to increase the capacity of the installation as required?*

For the reply to this see Questions 5 and 6. The S.N.C.B. points out that it is possible to extend an installation by 1° adding storage relay groups; 2° replacing a given selector by one of larger capacity, say for 35 locations instead of 28; and 3° adding a second transmitting and receiving group and a second receiver, with an additional line wire.

16, *b*). — *What is the duration of transmission of an order and a control impulse?*

From 3 to 4 seconds for a control and the same for a return proving indication. In the S.N.C.F. system to send out a control takes 3/10 second, without pre-selecting through a calling code, and one second in the opposite sense. Sending out a control and receiving the return indication occupy an average of one to three seconds, plus the time taken for the apparatus to which they refer to operate.

16, *c*). — *Is an operation order controlled before it is carried out? What steps are taken to make sure that dispensing with a preliminary control will not allow a*

shunting order wrongly received to be carried out?

With the exception of the C.F.F. (Switzerland), there is no return proving indication prior to a control taking effect. The sending out of a false control by reason of some alteration occurring in a code is considered very improbable. Moreover, any defect in the remote control can have no effect on the safety of the working as the interlocking is effected at the subsidiary locations. The S.N.C.B. to meet the case of a code impulse becoming irregularly lengthened, uses a special relay which in that event restores the remote control apparatus to its initial condition, and sends out the code afresh.

16. *d*). — *Are the orders recorded and kept? In what order are the recorded orders transmitted?*

Generally speaking the controls are both pre-selected and stored in the transmitter and sent out in a pre-determined order, usually that of the increase in the code indices. Controls have priority over return indications. In the S.N.C.F. system, the need to send out a deferred code does not arise. On the other hand, the storage of codes as they are received is often arranged for. The F.S. state that codes can be pre-selected but not stored.

16, *e*), *f*). — *How are the controls recorded?*

What method do you use if several controls use the same circuit simultaneously?

The return indications are held by means of repeating stock relays. The priority of transmitting them is sometimes determined by the order of their indices. Generally a location not transmitting has priority over another which has just done so, although it may have return indications waiting to be transmitted.

QUESTION 17, *a*). — *What types of relays are used? Telephone relays with neutral and polarised armature? What is the size of the magnetic system, coils, cores and armatures? What is the maximum number of contacts and what types of contacts are used?*

b). — *Have the relays brazed contacts, interchangeable screw or knife edge contects?*

Telephone type relays are used but generally of a somewhat larger and more finished design than usual in order to improve their characteristics. They are neutral or polarised, according to their function. Table II gives the details communicated to us on this subject.

QUESTION 18. — *D.C. coded systems work slowly. Are these systems also used on lines with heavy traffic ,and in that case, what methods are used to meet the requirements of this traffic?*

The Managements consulted consider the speed of working of the systems they have adopted as satisfactory in each particular case. It is reported in connection with Question 5 that the S.N.C.F. in its C.T.C. installation at Dijon has applied 3 line wires and the same number of distinct sets of equipment in order to obtain the required conditions of speed and flexibility. The coded S.N.C.F. system is faster in operation than the code systems using 16 or more impulses and appears to be better adapted to the remote control of large stations where there is very heavy traffic.

QUESTION 19. — *In telecontrolled stations have you direct or indirect locking points and for what reasons? Who keeps the key? Is there a telecontrolled electric lock? If there is no such lock, is it possible to work a point directly or must permission be obtained by telephone?*

Yes. The most usual procedure is to bolt any points on main or passing loop tracks not remotely controlled. They are unbolted from the central apparatus on

TABLE II. — **Relays used in Remote Control Equipment**

Characteristics	*Spain* RENFE	*France* S.N.C.F.	*Italy* F.S.	*Switzerland* C.F.F.
Length of coils.	20 × 20 × 16 cm (overall dimensions)	6 to 8 cm.	—	350 to 500 mm² (winding)
Diameter of coils. . . .		3 cm	—	
Number of contacts . .	12 or more	8 to 12	16	6 to 8
Type of contacts	silver to carbon	gold-silver alloy	silver	silver
Connections	soldered individually : plug connectors for all groups or sets of relays	soldered individually : plug connectors for all groups or sets of relays	soldered individually : connectors plug for all groups or sets of relays	soldered individually : plug connectors for all groups or sets of relays

request sent by telephone. There is either an electrically operated bolt operated directly by remote control or else a key normally held fast in a lock electrically released by such control. In other cases (RENFE) the bolting of the points takes place when the remotely controlled signal is cleared. When the signal is at danger and the approach track locking section unoccupied the points can be unbolted at will. (A padlock prevents unauthorised individuals from manipulating the bolts.) The unbolting is made known at the central apparatus by a red lamp on the operating panel.

QUESTION 20. — *By what system are the telecontrolled apparatus fed (relays, signals, motors for the points, etc.)?*

Power for remotely controlled appliances is provided locally with the type of current, voltage, and other arrangements used by the Managements concerned in connection with equipment not remotely controlled. As to the actual remote control apparatus itself, this is generally fed with D.C. at a voltage of 12 to 48, most often by batteries kept charged on the « floating » principle.

QUESTION 21. — *Do you use electric heating or some other methods of heating for telecontrolled points? How do these devices work and are the results obtained satisfactory?*

Yes. On the S.N.C.B., S.N.C.F., and C.F.F. lines. The S.N.C.B. allows a rating of 1 kW per point tongue. The C.F.F. consider 500 watts per metre of tongue to be necessary.

QUESTION 22. — *Are the telecontrolled posts equipped with a local control device (control table or some other such)?*

The remotely controlled junction installations in Belgium and Italy have a local frame or panel. The RENFE applies local electrical operation to its remotely controlled points.

QUESTION 23. — *Amongst the breakdowns listed below, which are signalled to the central post and which are not? Give the annual number of each type of breakdowns :*

a) *breakdowns in transmission?*
b) *breakdowns of the points?*

c) *signal lights burnt out?*

d) *failure of the relays of the local post to function?*

e) *interruption of the current?*

f) *other breakdowns?*

Generally speaking, faults in the transmission are notified to the central apparatus, also faults in the working of the points and relays as well as any interruption of the current. This is done either directly or indirectly (for example by the conditions produced, in the case of a relay failure). The burning out of signal lamps is not indicated at the central apparatus, except in Belgium, but at the lineside location or with automatic signals arrangements are made to indicate either a failed red lamp or at times some other one; in these cases the result is to hold the next signal in the rear at red.

In Table III the particulars received on the subject of failures are summarised.

TABLE III. — **Failures per Annum**

Failures	*Belgium* S.N.C.B. (1)	*France* S.N.C.F. (2)	*Switerland* C.F.F. (3)
In transmission	1	4	1
Points	4	27	none in service
Signal lamps	6	6	0.5
Relays (local)	10	3	very rare
Failures of power	5	44	very rare
Other cases	—	69	0.5

(1) Soignies Junction.
(2) Montereau signal box, and C.T.C. from Dijon and Paris (St. Lazare).
(3) 5 remote control layouts with axle counters.

QUESTION 24. — *Does a breakdown in a telecontrol line or a telecontrol post affect the other telecontrolled posts?*

It depends on the nature of the fault whether it affects all the locations branched off the line circuit, or only those situated beyond the fault. In principle, faults will affect the whole of the installation when the various locations are connected in series but only beyond the point of failure when they are connected in parallel.

QUESTION 25, *a*). — *How are the points and signals operated when anything goes wrong with the long distance telecontrol?*

b). — *Have you made provision for the operation of the points and signals locally by disconnecting the telecontrol or by connecting the signals of the through roads for through running? Can these changes in the connections be carried out in terms of the direction of the traffic or even independently for entering and leaving?*

In the case of points manual working is resorted to. The signals are held at danger and have to be passed under special authorisation (see Question 26). Where there is a local operating frame, panel or equivalent apparatus, this is disconnected from the remote control from the central apparatus, after an understanding on the telephone, and is operated in accordance with the rules provided for such a case. Sometimes the changeover to local working is itself remotely controlled.

QUESTION 26, *a*). — *What measures are taken, when as the result of a breakdown, a stop signal guarding the entrance or exit of a station cannot be cleared? Who gives the order authorising running past it at danger and by what means?*

The person in charge of the central apparatus has, as a rule, the duty of authorising by telephone a train crew to pass the signal. In certain cases (Belgium) the signals are equipped with a small marker light, which can be lighted to give the permissive signal by the actuation of a normally sealed push-button at the signal box in advance.

26, *b*). — *When, owing to a breakdown, a telecontrolled point does not correspond to the order given, how and by whom is it operated and with what guarantees is this operation done?*

The manual operation of the points is effected by either the train crew or the station staff, according to circumstances. The giving of the authorisation or handing out of the key or other appliance, as the case may be, to enable the points to be operated is effected by the person responsible for the working of the traffic, in accordance with the rules in force.

QUESTION 27, *a*). — *How are the routes freed when —*

i) *a change of route is necessary?*

ii) *there is a breakdown?*

Has provision been made for an order for the urgent freeing of a route? What time elapses after the signal goes to danger before the route is automatically freed? Is this also provided on lines where the trains follow one another very closely?

b). — *What technical telecontrol steps are taken to free a route urgently? Have route controlling devices time relays which only allow the freeing of the route.*

Generally speaking, routes may be released manually and the signal replaced to danger at any time, providing the approach locking section has not become occupied. If it has, then in order to release the approach locking it is necessary to : 1° replace the signal to danger by using an emergency switch; 2° release the route, by using the handle or other device employed to set it up; this can only take place if the signal is proved to be at danger and at the end of a certain interval determined by a time release. In systems having individual operation of points, there is also a special device which puts the signal to danger and frees the corresponding interlocking, in operation when the signal is at « clear » after a pre-determined interval.

In the case of certain failures (e.g. of route locking) a competent official has to effect the release by means of an emergency device, generally kept sealed.

QUESTION 28. — *What steps must the head of a C.T.C. post take if anything goes wrong with the cable and interrupts the telecontrol? (No impulses go out, no repetitions come in.)*

The person in charge of the central apparatus communicates by telephone with the lineman and if the fault cannot be immediately rectified, he instructs the stations, using any telephone circuit which may be available, to work as if the C.T.C. did not exist, or use the local means of operating the points, etc., where such is provided.

QUESTION 29, *a*). — *Does the head of the Central Post keep graphs showing the way the traffic operations take place? Does he insert the announcements received on the graph representing the line?*

b) *Is there any automatic equipment recording the running of the trains? Of what type? (Short description.)*

c). — *What sections of track are controlled by the equipment recording the running*

of the trains? Is the direction of running specially shown?

The person in charge of the central apparatus makes out a graphic of the actual movements of the trains unless there is an automatic recorder as in the RENFE installation. This has a paper band which moves vertically and is ruled with horizontal lines representing two minute intervals. There is a stylus pen for each station arrival or departure section, which makes a small mark whenever such a section becomes occupied, whatever the direction of the train movement.

QUESTION 30. — *In the case of double track lines how do you safeguard passengers who have to cross over the other line to board or leave a train?*

This case is not met with by the majority of managements consulted. The S.N.C.F. arranges for one of the staff at the station to see that no danger is incurred by passengers having to cross a line.

QUESTION 31. *a*). — *On lines equipped with C.T.C., are the number and type of the trains announced in any way to the central post?*

b). — *Are the number and the type of the trains shown optically on the control table of the central post at the same time as the occupation of a section of track?*

c). — *Do you announce the number of the train and its type to the stations or only the type or only the destination?*

As a rule the number and class of trains are notified by telephone to the central apparatus in accordance with the particular traffic working regulations. Notifications of train movements are sent out to the stations also by telephone. In certain cases all that is done is to advise them of any alteration in the normal order of trains. The S.N.C.B. contemplates using a system of indicators actuated by push-buttons and the F.S. for future work, proposes to show the number and class of train on the central panel, but no information has been received on the technical details of the apparatus in view.

QUESTION 32. — *What telephonic connections have you made between the central post and —*

a) *the local posts?*

b) *the signals?*

c) *the maintenance men?*

Ordinary telephone arrangements are used in the three cases. The apparatus for calling to the telephone, placed at absolute (« controlled » or « semi-automatic ») stop signals is often remotely controlled, a bell or lamp being used to attract the trainmen's attention.

QUESTION 33. — *What organisation have you set up for the maintenance and conservation of the installation? How many men are needed for the systematic overhaul and how is this carried out? How are breakdowns and possible damage repaired at the Central Post, in the transmission line and in the local posts?*

The managements having a certain amount of experience with remote control equipment consider that its maintenance offers no particular difficulty. We reproduce below complete the reply received from the S.N.C.F., this Management having the greatest number of installations of this kind and having used them for a long time. (C.T.C. at the Gare St Lazare, Paris 1933.)

« The relays composing these installations are grouped according to their function in sets of assemblies, in dust-proof containers with plug connectors. The maintenance staff have reserve sets which, in case of need, can be substituted immediately for those in use.

Owing to the good class of material used failures are extremely rare and the installations do not call for any maintenance in the strict sense of the term, beyond inspection at certain regular intervals.

The apparatus units, sealed at the maker's works, are re-conditioned periodically in the workshops, reserve equipment being put in

place whilst this is being done. The period between overhauls is several years, but varies with the intensity of the service demanded of the equipment.

The present cabled circuits likewise demand no maintenance as a rule spare circuits are provided along the line, so that in case one fails, another may be quickly substituted for it.

The number of maintainers employed on the Blaisy Bas-Dijon C. T. C. installation is 20. »

SUMMARY OF CHAPTER I.

— Remote control of signalling installations is being extended and developed in two distinct ways :

a) for the control of stations (generally small ones) *along a length of line* (C.T.C.) :

b) for the control of groups of points and signals in areas situated at some distance in large station layouts, or of the apparatus at a junction or crossing between lines, the actual control in this latter case being effected from the nearest station.

— On *single lines* C.T.C. is being applied to increase the capacity of heavily worked sections (thereby avoiding doubling) and at the same time to realise a saving in staff even on lines not working to capacity. The importance of the results obtained in these two cases depends on the local conditions and in particular on the circumstances obtaining on the line prior to the equipment being installed. Where there is already a dispatcher, or traffic controller, or automatic signalling is being used, or the points and signals in a station are being worked from a signal box or its equivalent, the specific advantages to be derived from C.T.C. will be more limited.

— C.T.C. is to be recommended for *double lines* when it is a question of making use of tracks for trains in either direction of running at will, in order to obtain a much greater traffic capacity and avoid having to lay down additional tracks. The best results are obtained when the periods of maximum load on the two tracks are not coincident and the number of cases where a train requires to be shunted is high in consequence of there being successions of trains running at different speeds.

— Remote control applied to the electrical operation of points and signals in areas around large stations and at nearby junctions, etc., seems to have acquired a considerable degree of development as a result of certain advantages of varying kinds which it offers, as for instance the possibility of realising savings in operating staff by concentrating the control of the traffic over areas of considerable extent in a single signal box; greater rapidity and flexibility of working, as a consequence of the suppression of a multiplicity of signalmen and of the signalling operations they have to go through in cooperation with each other; reduction in first costs, especially in the matter of cabling, a reduction becoming increasingly of value as the number of appliances remotely controlled increases and their distance from the central signal box; reduction in the number of wires thereby obtained, giving an equivalent reduction in the probability of a fault occurring or a false connection between wires, such in any case then only affecting a reduced area of the installation.

— Areas worked under remote control are all provided with track circuits (or an equivalent, such as axle counting) to indicate the state of the lines and movement of the trains. The C.T.C. installations are completed frequently by the application of automatic signalling especially when it is desired to obtain the maximum traffic carrying capacity. Only the non-permissive (that is, the absolute stop) signals protecting points and crossings are as a matter of course remotely controlled.

— The transmission systems used for remote control employ D.C. impulses which vary either according to the time taken up by the emissions and interruptions of current, or the polarity of the emissions and sometimes according to the particular wires over which the impulses are transmitted. The first system (code of long and short

impulses) is by its nature slower than the second for an equal number of distinct codes which a particular installation comprises. The first system is the one most usually employed for C.T.C.; the second appears to be preferred for remote control of areas around large traffic centres.

— The technical arrangements adopted vary as regards the number of wires required and the manner in which they are used for the various functions according to whether the line circuits are normally energised or not, depending on the method of connecting up the local selector relays (in parallel or series) and whether chains of relays or rotary selectors are employed. The experience obtained so far by the various Managements does not appear to be sufficient, owing to the somewhat small number of installations as yet at work, and the short time some have been in service, to enable conclusions to be come to as to which particular type of equipment is to be preferred for a given kind of installation.

— The interlocking in these installations is, as a matter of course, effected in the apparatus at the local, or subsidiary locations and consequently is independent of the remote control proper. In this way any failure or wrong transmission in either the control or the return indication will have no effect on the safety of the working and at most can only cause some delay. For this reason the majority of Managements do not prove the correctness of the controls before such take effect.

— The numerous relays requiring to be used in this type of work are of the telephone pattern, but an endeavour is made to improve their design by better manufacture and finish, and by making certain parts larger and more robust so as to bring them more into line with the types of relay generally used to date in signalling work.

— The capacity and flexibility of C.T.C. systems, having in mind their possible development, has to be considered under several aspects; the number of subsidiary locations able to be controlled along a length of line; the number of controls and return indications which each can deal with; the capacity of the system and line circuits used with it to transmit without delay inimical to the flexibility of the train working the number of control and return indications called for by the traffic density and the amount of apparatus needing to be remotely controlled. This last consideration is of considerable importance in the case of remote control over an area where there is heavy traffic, and is of a character to lead to the selection of the more rapidly working systems using a greater number of line wires for transmitting the codes. In a C.T.C. installation covering a length of line the use of pre-selection and storage arrangements for the controls and return indications allows of a 2-wire line circuit being generally found sufficient.

— The maintenance of remote control installations does not appear to offer any special difficulty. Failures are in general few, thanks to the progress achieved in producing good quality equipment. Relays are grouped on assemblies, each allocated to particular functions and mounted in dust-tight containers with plug connectors. If any item in such an assembly becomes defective its replacement by a reserve unit can be effected at once. The period of overhaul of the various pieces of apparatus is in general one of several years, but varies according to the intensity of the service each is called on to render.

CHAPTER II.

B. — Electric working and control devices for hinged and « flexible » points and switches.

Control of accidental trailing of the switch blade.

The Managements which replied to this part of our questionnaire are :—

Belgium and Colony.

Belgian National Railways.
Office d'Exploitation des Transports Coloniaux (« OTRACO »).
Matadi-Leopoldville Ry.
Lower Congo to Katanga Railways.

Spain.

Spanish National Railways (RENFE).

France and French Union.

French National Railways.
Moroccan Railways.
Régie des Transports Parisiens.

Italy.

Italian State Railways.

Luxemburg.

Luxemburg National Railways.

Portugal and Colonies.

Portuguese Railways.

Switzerland.

Swiss Federal Railways.
Rhaetian Railways.
Berne-Loetschberg-Simplon Railways.

* * *

Electrical operation of points has been in use for a long period on many Railways. On many lines the development of the engineering details of such working can be followed from the installations carried out at different times and still in service. We shall limit ourselves to setting out the arrangements which various Managements have adopted for their modern installations and shall refrain from referring to those still in use but of a type which will not be installed in future.

Points.

QUESTION 1, *a*). — *Do you use points with or without locking of the switch blade and why ? (By locking of the switch blade is meant a device which locks each of the blades or the closed blade only, unlike a pull-rod lock which locks the stretcher rod of the blades.)*

Yes. The bolt on the point tongue is used in the case of points normally taken facing by trains, except in Italy (F.S.), Portugal (C.P.), Switzerland (C.F.F.). In Spain (RENFE), it is used only when the point machine is of the type having a single drive rod.

The bolt on the point tongue is easily incorporated in the arrangements applied to make the points trailable, while allowing both tongues to be actuated by one drive rod.

1, *b*). — *Is the electric device for operating the points fixed or moveable and why?*

The point machine is fixed to the sleepers carrying the points themselves and sometimes to the stock rails; it is therefore fixed in relation to the track. This is a simple arrangement and renders the adjustment independent of any movement of the track.

1, *c*). — *What is the sweep of the switch blades and the stroke of the motor when points with blade lock are used?*

	Travel of point tongues	Stroke of point machine
Belgium (S.N.C.B.)	160 mm (6 5/16")	240 mm (9 7/16")
Spain (RENFE)	170 mm (6 11/16")	220 mm (8 11/16")
France (S.N.C.F.) — (C.F.M.)	150 mm (5 23/32")	248 mm (9 3/4")
» (R.A.T.P.)	165 mm (6 1/2")	217 mm (8 17/32")
Italy (F.S.)	170 mm (6 11/16")	
Portugal (C.P.)	140 mm (5 1/2")	160 mm (6 5/16")
Switzerland (C.F.F.)	160-170 mm (6 5/16-6 11/16")	240 mm (9 7/16")

In Belgium the stroke of the machine in the case of heel-less points is 300 mm (11 13/16").

1, *d*). — *What sort of blade lock do you use?*

Belgium (S.N.C.B.) — (OTRACO).	Bussing lock
Spain (RENFE)	clamp type lock
France (S.N.C.F.)	enclosed tongue lock
» (R.A.T.P.)	RATP's own lock & hoock lock (derived from Saxby)
» (C.F.M.)	enclosed tongue lock

1, *e*). — *How is the stability of the position of the blade assured when points without blade lock are used?*

Generally the point machines include a mechanical locking attachment which holds the driving rod or rods.

1, *f*). — *What other types of lock do you use?*

The S.N.C.B. uses in the case of heel-less points an operating device which becomes locked at the end of the stroke. The C.F.M. uses the P.L.M. type lock, the R.A.T.P. the Bardot, and the C.F.F. the Bruchsal lock.

QUESTION 2, *a*). — *Are there special locks for trailable points and derailing switches?*

None of the Managements consulted has points operated electrically which are intended to be trailed in ordinary regular working, except in marshalling yards, where the points are not bolted.

2, *b*). — *Are points with locks trailable or is the lock fixed?*

Bolted points are not trailable on the S.N.C.B. (in the case of heel-less points), S.N.C.F., R.A.T.P., and C.F.M.; they are in Belgium (in the case of heeled points), Spain, Italy, Portugal, and Switzerland. (This does *not* apply when a bolt, *additional* to that of the facing point mechanism itself is meant.)

2, *c*). — *Is the locking device mounted on the operating mechanism or is it independent of the latter?*

Yes. The bolt, or lock and the driving parts of the equipment are mutually dependent, one moving the other.

Control of points.

QUESTION 3. — *The following safety measures are taken as being included in the control of electrically operated points :—*

a) Internal electric control that the bar or part that moves the two blades of the point connected by a rigid or articulated stem, has travelled its whole stroke.

b) Internal electric control that the two bars which move the two blades independently when these are not rigidly connected, have completed their respective strokes.

c) Internal electric control that the bars or moveable parts mentioned under a) and b) above are still locked after they have completed their stroke. State, in the case of an independent bar for each blade, whether the blade in contact with the stock rail alone is locked.

d) Control by means of electric contacts worked directly by the blades, that the point of the fixed blade is in the correct position. Please indicate whether this verification is done for each of the two positions of the points (through road and turnout road) or only for the former.

e) Control by means of contacts as under d) of the correct position of the point of the open blade.

f) Mechanical locking of the points of the blades, worked by the own working of the point by means of a supplementary stroke of the bar moving the blades (for example hooklock).

TABLE IV. — CONTROL OF POINTS (PRINCIPAL TRACKS).

ADMINISTRATIONS	*Adopted controls* (Question 3)					
	a	*b*	*c*	*d*	*e*	*f*
Belgium (S.N.C.B.)	yes	—	no (yes on heel-less points)	yes (*)	yes (*)	yes
Spain	yes	—	yes	yes (*)	yes (*)	yes
		yes	yes	yes (*)	yes (*)	yes
France (S.N.C.F.)	yes	—	no	yes (*)	yes (*)	yes
France (R.A.T.P.)—(C.F.M.)	yes	—	yes	yes (*)	yes (*) (C.F.M.)	yes
Italy (F.S.)	—	yes	yes	yes (*)	yes (*)	yes
Portugal (C.P.)	—	yes	yes	yes (*)	yes (*)	yes
Switzerland (C.F.F.)	yes		yes (blade in contact)	yes (*) (for S > 47 m/h)	yes (*)	Tudel lock

(*) Both positions of points are controlled (direct track and deviated track).

How many of the checks described under a), b), c), e) and f) or others not mentioned, either alone or in conjunction with each other do you use in your up-to-date installations of facing points and crossings (according to whether they are on the main lines, secondary lines or marshalling groups), and for trailing points and crossings, and what are the maximum speeds authorized for running through facing points?

The replies received to question 3 are given in Table IV above: they concern points taken facing by trains, although certain Managements also equip trailing points similarly. Under *f*) we indicate as « positive » the case where there is a mechanical bolt or lock acting on the point tongue (point tongue bolt or the like) but not a bolting or locking effect in the internal mechanism of the point machine. This latter arrangement is dealt with again under *c*).

On main running lines the detection referred to under *d*) and *e*) generally acts in the form of what is called « imperative » detection or « constant » detection, acting on the signals themselves.

The maximum speeds allowed over points are the more often determined entirely by the characteristics of the track. The C.F.F. lay down a maximum of 75 km (46 miles)/h over points taken facing when not provided with direct detection of the tongues.

QUESTION 4. — *When do you use direct control of the points of the two blades? Do you prefer to use a single apparatus in which the two blades are checked by means of the stems?*

This question does not arise because the detection covered by *d*) and *e*) (Question 3) is effected inside the point machine. When it is effected outside it, France uses separate detection for each tongue. In Spain, the two detector rods act on a single detector.

QUESTION 5. — *a) Do you use the same arrangements or different devices for the electric operation :*

i) *of normal points ?*

ii) *of points difficult to operate ?*

iii) *of points on the slopes of gravity marshalling yards ?*

b) What force operating time and controlling force are ordered for these three types of points and what are the other requirements prescribed ?

c) What are the different gear ratios used for these three same sorts of points ?

d) Do you use different operating devices for articulated points and for flexible points, and why ?

e) Can the operating device be installed at will on either side of the point ? Is it rectilinear or angular ?

f) When the motors are supplied with current by local batteries what is the allowable operating time and what voltages are used ?

Generally speaking, different operating arrangements are used, the one for normal types of points, the other, very rapid acting, for points in hump marshalling yards. In Belgium (S.N.C.B.) a third type is used developing a greater driving force and having additional bolting and unbolting strokes, for use with heel-less switches (see Table V).

QUESTION 6. — *a) What voltage and what type of current do you use for operating and controlling points in the case of steam traction, and in the case of electric traction using D.C. and A.C. supplies ?*

b) Is the current voluntarily reduced when the motor of the point begins to run ?

c) How many amperes does the motor absorb on starting and how much whilst running ?

d) Is the working current cut by the operating device or by the interlocking post ? Are there control contacts on the operating device or not ?

e) Do you stipulate motors that can operate on various kinds of current ?

f) Is the current for working the point taken to the operating devices of the points by a circular circuit, or is there a special circuit bringing the current from the interlocking post to each point ?

See the replies received as given in Table V.

QUESTION 7, *a*). — *Does the motor run in either direction, or has the operating device to be reversed ?*

The point machine motors rotate in both directions.

7, *b*). — *Do you use an operating device with worm or straight gear ? Are the teeth straight, oblique, or helicoidal ?*

7, *c*). — *What transmission arrangement do you use ?*

The S.N.C.B. and C.F.F. use worm or screw drive, except in the case of marshalling yard points, for which there is ordinary spur gearing, sometimes worm drive also, according to which manufacturer is concerned. The movement is transmitted to the points by rod connections.

QUESTION 8. — *In what cases and with what objects in view have you fitted in a local manœuvre device, also electrical in the case of points operated electrically from a distance ?*

Does this manœuvre organ require the consent of the Post to be previously transmitted electrically ? When the local electric manœuvre organ is used, do the electric interlocking safety devices work

ADMINISTRATIONS QUESTIONS		*BELGIUM* S.N.C.B.	*SPAIN* RENFE
(5*b*) Effort developed . .	heeled points	300 kg	300 kg
	points in marshalling yards	300 kg	400 kg
	heel-less points.	400 kg	—
Time of operation .	heeled points	4 sec.	3 sec.
	points in marshalling yards	0.7 sec.	0.8 sec.
	heel-less points.	7 sec.	—
(5*c*) Transmission ratio	heeled points	4.5/1 and 7.5/1	
	points in marshalling yards	3/1	
	heel-less points.	12/1	
(5*e*) Can the point machine be mounted on either side of the points, and in a direct line or otherwise		yes direct line	yes direct line
(5*f*) Operating time and voltages, using local batteries		—	10 sec. 24 V
(6*a*) Voltage and type of current for operating circuit	steam lines	d.c. 150 V	d.c. 110 V
	d.c. electric lines.		a.c. 110 V
	a.c. electric lines	—	—
Voltage and type of current for detection circuit	steam lines	d.c. 40 V	d.c. 24 V
	d.c. electric lines		d.c. 24 V rectified
	a.c. electric lines	—	—
(6*b*) Is the current arranged to be reduced at the starting of the motor?		no	no
(6*c*) Current in amperes at the starting of the motor, and when running	heeled points	7 A - 2 A	
	points in marshalling yards	8 A - 3 A	~ 7 A - 3 A
	heel-less points.	10 A - 4 A	
(6*d*) Where is the operating current cut off ?		to the motor	to the motor
Are there detecting contacts on the operating mechanism ?		yes	yes
(6*e*) Do the motors work with more than one type of current ?		no	no
(6*f*) Is the operating current conveyed to the point machines by a ring main, or is there a special circuit to each ?		special circuit	special circuit

FRANCE		*ITALY*	*PORTUGAL*	*SWITZERLAND*
S.N.C.F.	R.A.T.P.	F.S.	C.P.	C.F.F.
400 kg	400 kg	d.c. 120-180 kg a.c. 220 kg		min. 250 kg
500 kg	—			min. 250 kg
3 sec.	2 sec.	d.c. 1.5 sec. a.c. 3-4 sec.	maximum : 4 sec. (or 6 sec., on conjugated or mixed points	2-3 sec.
0.6 sec.	—			0.50-0.75 sec.
		0.03		
yes direct line	yes as regards to local possibilities	yes direct line	yes direct line	no direct line
12 sec.			—	—
24 V			—	—
3-phase 115 V 220 V 24 V				
3-phase 50 Hz 220V	d.c. 110 V a.c. 220 V 3-phase	motor d.c. 144 V	d.c. 110 V a.c. 220 V	standard : 180 V 16 2/3 Hz.
		motor a.c. 260 V 3-phse		emergency : 250 V 50 Hz.
115 V 24 V 220V 2-phase 83Hz			—	
115 V-24 V-50 Hz. 8 V or 24 V	a.c. 110 V	motor d.c. 48 V	d.c. 36 - 30 - 24 V a.c. 220 V	d.c. 36 V
115 V-24 V-50 Hz.	a.c. 60 V			
8 V or 24 V 115 V-24 V-83 Hz.		motor a.c. 150 V single phase	— —	
no	no	no (motor start empty)	no	yes by permanent resistance
~ 8 A - 4 A	12 A - 5 A (by phase)	d.c. 8 A - 3 A a.c.1 2 A - 5 A	5 ~ 6 A	10/15 A - 3 A
to the motor	Urban system : to the motor : Line of Sceaux : to the Post	d.c. : to the motor; a.c. : to the Poste	to the motor	to the motor
yes	yes	d.c. yes a.c. no	yes	yes
no	no	no	no	yes
by feeder : with relay control: by special circuit : with direct control	Urban system : ring main Line of Sceaux : special circuit	special circuit	special circuit	special circuit

and does the Central Post get a verification of the movements of the points?

Spain (RENFE), Portugal (C.P.), Switzerland (C.F.F.), and « OTRACO » use local electric operation for certain points. Permission has first to be given from the signal box which ordinarily operates the points from a distance. The RENFE uses this arrangement at the small stations with the object of shunting trains, which have to detach or pick up vehicles with the aid of a minimum of staff. Giving such permission locks at danger the relevant home and starting signals.

QUESTION 9, *a*). — *In urgent cases (interruption of the current, damage to the motor, overhaul of the equipment, etc.) is there some arrangement to enable the points to be hand operated incorporated in the electrical mechanism of the points?*

All modern machines allow of operating the points by hand, with the aid of a crank handle or lever.

9, *b*). — *If hand-operated, are the cables supplying the current cut out :*

i) *obligatorily?*

ii) *possibly?*

iii) *how is this done?*

With some Managements the disconnection of the feed wires is obligatory and effected automatically when the local hand operation device is released or placed in position. If there is no automatic arrangement a fuse must first be removed from the circuit, or a circuit breaker be opened.

9, *c*). — *If the points are operated by hand, must their position be advised to the signal box?*

This is unnecessary. In the signal box the fact that manual operation is in force is made known by the detection circuit, as soon as the position of the points no longer agrees with the controlling handle or lever.

9, *d*). — *How do you assure the correspondence between the points and the route when a point whose electrical control is out of order is worked by hand?*

In this case a written order, issued under an appropriate regulation, authorises the driver to pass the signal at danger. The S.N.C.B. continues, however, to prove or make certain of the position of any points in connection with the clearing of a signal protecting the route of which such points form a part.

QUESTION 10. — *Is the employee in charge of the maintenance able to prevent the working of a manœuvre device while he is carrying out work of a minor kind on this device?*

Yes, by cutting off power from the point machines, either at the machine or in the signal box.

QUESTION 11. — *What measures and special devices have you adopted to make impossible an irregular and uncontrolled movement of the points and false controles due to the supply lines being crossed, defects in the insulation, or inductive effects?*

Both the controlling and detecting circuits are very carefully arranged so as to reveal, in various ways, any defect in the insulation which may arise. We give below a summary of some of the replies received to this question

S.N.C.B.

In the new circuit schemes for use on electrified lines, the return control circuit is an insulated wire in the cable. The return for the detection circuit, however, is taken over the wire which serves to convey the next control current and a differentially wound relay interrupts this detection circuit if an earth comes on, or any unbalance occurs between feed and return circuits.

S.N.C.F.

Controls and detections are generally effected by polarised circuits and polar 2-element detector relays, which prove that the apparatus on the ground is in a condition agreeing with that of the controlling levers or handles. Special precautions are taken to prevent any reversal of the connections to the 2-element detector relay occurring during routine maintenance work.

The effects of induction are negligible on the controlling circuits, taking into account the power needed to operate a point machine.

For the detection circuits various kinds of current are being used (D.C., A.C. at 50 or 16 2/3 cycles) according to the nature of any other current that is to be feared as likely to exercise a harmful inductive effect.

F.S.

Under normal conditions all control circuit wires are open at the signal box. In the case of D.C. point machines these wires are connected in short-circuit with the coil of a maximum current cutout inserted in the connection. Should a false contact between wires arise, this cutout breaks the feed connection to all wires in the same cable. The detection circuit is also arranged to have both double pole break and short circuit protection.

QUESTION 12. — *Do you consider it advisable, in general or in special cases, that the electrical operation of points should be reversible and repeatable several times when the presence of an obstacle (snow, stone, etc.) prevents the blades from travelling their full distance, and the verification of their final position is not possible?*

Almost all Administrations consider it useful to have electrical operation of points reversible and capable of being repeated at will by the signalman actuating the lever or handle.

QUESTION 13, *a*). — *What are the statistics of breakdowns classified according to their type : total number of breakdowns and % of trains held up, % of accidents resulting in relation to the number of trains run or the number of times the points are operated?*

The Administrations consulted have not been able to draw up failure statistics of a form which will allow of useful comparisons being made.

13, *b*). — *How many working days does the maintenance of the points operating mechanism involve per annum?*

The maintenance of an electric point layout including all rod connections, appears to demand about 50 to 75 hours work annually, varying with the country concerned.

Trailing points.

QUESTION 14, *a*). — *In what cases and for what reasons do you equip points with a trailing device which prevents damage being caused to the points and their motor?*

In Belgium (S.N.C.B.), Italy (F.S.) and Portugal (C.F.) heeled points are regularly trailable. The S.N.C.F., R.A.T.P. and C.F.M. limit trailability to points in marshalling yards and certain sidings. The RENFE uses these arrangements in every case where shunting not controlled by signals can take place, and in special circumstances where it is to be feared that signals may be passed accidentally at danger.

14, *b*). — *Explain the principles on which the trailing devices you are using work on electrically operated points with or without blade lock :*

i) *case of blades moved independently by the motor mechanism;*

ii) *case of blades connected together by an articulated stem;*

iii) *case in which the blades are rigidly joined by a stem.*

State :

1°) How are they unlocked (if there is an interior or exterior lock) ?

2°) Whether the transmission is reversible and whether the trailing forces the motor to turn ?

3°) Whether accidental trailing uncouples the mechanical transmission from the electric motor and by what means ?

The unlocking (whether effected in the machine or outside it) of the closed point tongue is brought about by the force exerted on certain parts of the equipment, according to the design of the particular manufacturer, through the wheels acting on the open tongue, necessarily the first to become displaced when trailability occurs.

Certain railways (S. N. C. B., RENFE, C.F.F., C.P.) have a non-reversible mechanism in the machine and trailing does not drive the motor itself backwards. The mechanical transmission becomes disconnected from it by a clutch, of the friction or other type.

Other systems use a reversible transmission which takes the motor with it (F.S. in the case of D.C. point machines).

14, *c*). — *How does the Central Post know that trailable points have been trailed ? What effects has this upon the subsequent setting up of routes ?*

When a pair of points becomes trailed, that is indicated in the signal box by the action of the visual detection indicator, to which attention is drawn by a bell. Subsequent preparation of a route which includes the trailed points requires first that the detection circuit shall be re-established by bringing the points into agreement with their controlling handle or lever.

14, *d*). — *Have you any regulations concerning the maximum speeds at which such points can be trailed ?*

Electrically operated points should not normally be run through trailing, in ordinary working, and there are therefore no regulations referring to the maximum speed at which that is permissible. Actually the speed is generally very low, seeing that it is chiefly during shunting that a run through occurs.

14, *e*). — *Have you carried out trials, and with what object, of a type of points mechanism, which after having been trailed forces the blades to complete the movement caused by the trailing until the points are set for the line in the trailing direction ?*

This type of machine, trailable and reversible, is used as normal practice by the S.N.C.F. in the case of marshalling yard points. The RENFE is trying it for points at small stations on single lines where traffic is heavy, with the object of eliminating the annoying type of accident which occurs when after a movement has trailed the points it sets back again suddenly before all the vehicles have passed through.

14, *f*). — *What steps do you take to reduce to the minimum the damage caused to and the time taken to repair non-trailable points when a trailing accidentally has occurred ?*

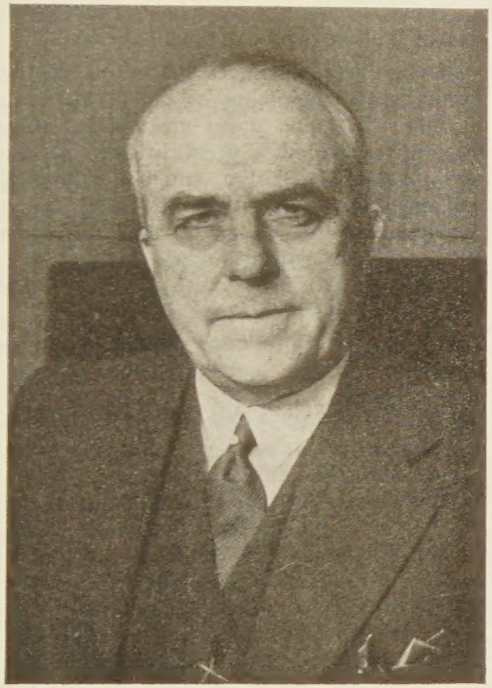
With this object some part of the equipment is arranged to become permanently deformed or broken; this limits the extent of the damage caused by trailing the points.

[385. (09 .2]

OBITUARY.

Gustaf DAHLBECK,

Former General Manager of the Swedish State Railways,
Former Member of the Permanent Commission of the International Railway Congress Association.



M. Gustaf Dahlbeck, former General Manager of the Swedish State Railways and former Member of the Permanent Commission of our Association died on the 10th April 1953, at the age of 70.

M. Dalhbeck was born in 1883 at Oestersund. He matriculated in 1901 and obtained his engineering diploma at the Stockholm Royal Polytechnic, Road and Bridges Section, in 1906. He was employed from 1906 to 1909 by the Southern Region of Roads and Bridges as assistant engineer; he became engineer of railway constructions to the Swedish State Railways between 1909 and 1915, then Permanent Way Engineer from 1915 to 1916. In 1916, he was given the charge of a Section of the Permanent Way Department, a post which he held until 1926. His brilliant qualities caused him to be appointed Regional Manager in 1927, first of all at Lulea, in the north of Sweden, and afterwards at Gothemburg.

The great reputation, he acquired during his noteworthy career in the different Departments under his care, resulted in his being appointed General Manager of the Swedish State Railways in 1938. He held this post until 1948 and during the ten years in question, he had to make many important decisions such as the extension of the electrified system and the speeding up of the work of electrification. He was concerned above all with increasing the speed of the motor stock, which went up from 90 to 120 km (55 to 74 miles)/h, increasing the number of train services, and improving the timetables. He attached very great importance to reinforcing the main lines, as well as to building double track lines, most of the lines being up till then single track ones and these measures had the result that communications were facilitated and bottle-necks avoided. During M.

DAHLBECK's management, perhaps even more than previously, the Railways had to endure and fight the pitiless competition of road transport; but thanks to his organising genius, he succeeded in maintaining and even extending the field of action of the Railway. He also devoted some of his talents to the organisation of the road services, which completed the railway network.

The war unfortunately put paid to many of M. DAHLBECK's plans, though he did not allow it to throw him off his course. Naturally, this situation imposed new and heavy responsibilities upon him.

In spite of all the preoccupations the war caused him M. DAHLBECK had the satisfaction of seeing the Swedish State Railways enjoy a very sound economic position, with the receipts greatly exceeding those of previous years.

The idea of the four great Railway Administrations of the North of Europe collaborating both as regards stock and staff as well as the general collaboration of European Railway Administrations was much favoured by M. DAHLBECK.

Since 1932, M. DAHLBECK was a Lieutenant-Colonel of the Royal Corps of Roads and Bridges.

Finally, we would quote once again the eulogistic lines of his successor M. Erik UPMARK, who expressed himself as follows :

« It is with great regret that we record the passing of our devoted Colleague who, humbly, with the whole of his physical and spiritual strength, devoted himself to the mission imposed on him, and until the very last hours of his life, and we would like to record our gratitude to him. »

M. DAHLBECK was elected Member of the Permanent Commission of our Association in 1938. In spite of his absorbing duties, he always showed a great interest in the work of our Association, and was a faithful and devoted collaborator. He took part in the last post-war Congress at Lucerne in 1947, as representative of the Swedish Government and the Swedish Railways. He resigned on his retirement in 1948.

We wish to express our sincere sympathy to his family.

THE EXECUTIVE COMMITTEE.

NEW BOOKS AND PUBLICATIONS.

[**621** .13 (02, **625** .25 (02 & **625** .28 (02]

LAMALLE (U.) Ingénieur civil des Mines A. I. Lg., Directeur général honoraire de la Société Nationale des Chemins de fer belges, Professeur émérite de l'Université de Louvain, **Cours d'Exploitation des Chemins de fer.** *Tome IV* : **Traction à vapeur, Traction électrique, Traction Diesel, Freinage.** — *(Railway Operating Course. Volume IV : Steam Traction, Electric Traction, Diesel Traction, Brakes)* — Second edition, — One volume (7 7/8 × 10 1/4 in.) of 312 pages, with 227 figures and tables. — 1953, Louvain : Librairie Universitaire, Uystpruyst, publishers, rue de la Monnaie, 10, and Paris : Dunod, publishers, 92, rue Bonaparte.

Some ten years have passed since the issue of the first edition of this work of M. Lamalle (1). During this period, the operating methods and equipment of railways, especially the traction rolling stock, have undergone a considerable evolution.

Electric traction has continued to extend and new applications have been made. The Diesel engine has won an important place in equipping locomotives and railcars. Locomotives of special types have recently been designed. And the classic steam locomotive, valiantly holding its own against all these competitors, has undergone altogether unexpected improvements.

On the other hand, the increase in the speed has led engineers to reconsider the whole question of braking.

It will therefore be appreciated that it has been a somewhat difficult task to bring this book up to date. It was facilitated however by the character of the book, which is concerned above all with the speculative aspect of things, referring the reader to other works for detailed descriptions.

The arrangement of the book has been modified. The introductory part dealing with traction which goes into the resistance of trains has been extended to include all present day examples.

The chapters on traction give substantial information on recent improvements and new applications of the steam locomotive, electric traction and Diesel traction. Attention is called in particular to studies of the exhaust, designing a steam locomotive, dynamometer trials and measurements, and the use of pneumatic tyres on railway vehicles.

As regards electric traction, we would mention as an achievement the realisations and proposed application of industrial frequency high tension current.

A study of the transmission justly holds an important place in the chapter dealing with railcars. The characteristics of Diesel-electric locomotives and Diesel shunting engines show the possibilities of developing this method of traction.

As for the question of braking, the application of the continuous brake to goods trains is gone into fully. The theory of braking has been revised and completed by the results of recent trials and a study of the stopping distances.

No attempt has been made to give a complete inventory of the additions which have enriched this second edition, nor to detail the complete scope of the book. From this point of view it will be sufficient to state that it offers a complete didactic treatise on traction and braking. The numerous concrete data given in a readily appreciated form give the theories and ideas developed invaluable support and meaning.

E. M.

(1) See May 1946 *Congress Bulletin* (page 107) for a review of the first edition.